Dragon Lake
General Water Quality
and Nutrient Loading in 1980

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Province of British Columbia Ministry of Environment

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Ministry of Environment
ASSESSMENT AND PLANNING DIVISION

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DRAGON LAKE
GENERAL WATER QUALITY AND NUTRIENT LOADING IN 1980

By

C.J.P. McKean

AQUATIC STUDIES BRANCH

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ABSTRACT

In 1980 the Dragon Lake Improvement District requested a detailed analysis of the sources of nutrients entering Dragon Lake, near Quesnel, B.C. This report summarizes the work completed by the Aquatic Studies Branch in 1980.

Dragon Lake has a calculated water retention time of 17 years in an average precipitation year. The high retention time (low flushing rate) is the result of low annual precipitation, and small watershed area in proportion to lake volume.

Because of the lake's shallowness, wind mixing prevents summer stratification. The result is warm, well oxygenated water at the bottom of the lake throughout the summer. During the winter, ice prevents wind mixing and winter stratification occurs. Anaerobic (no oxygen) conditions develop below 4 metres by late March. Winter fish kills may occur in the future if the degree of eutrophication increases.

Phosphorus theoretically is the nutrient limiting the growth of the phytoplankton community. However, preliminary evidence suggests the phytoplankton biomass is far below the potential estimated for B.C. lakes. Heavy zooplankton grazing of phytoplankton is a possible explanation for the low algal biomass.

Growth of rooted aquatic macrophytes, and of algae that form floating mats, was reported by local residents to have increased over the past several years. Increased nutrients are believed responsible.

Blue-green algae dominated the phytoplankton community on the two occasions samples were taken. The blue-green algae are believed responsible for the 'muddy' taste of trout taken during the summer.

Phosphorus concentrations have increased substantially since 1974. The 1980 spring overturn concentration was 39 µg/L. The phosphorus loading rate

was calculated from the spring overturn concentration using the Dillon and Rigler (1975) model. The 1980 loading rate was estimated to be 2235 kg or 0.34 $g/m^2/yr$. The main sources of phosphorus, listed in decreasing order of importance, were wind activity, livestock, septic tanks, inflow streams, crops, recycling from the sediments, and aerial input.

The 1981 phosphorus concentration was 22 µg/L. This is 45 percent below the 1980 spring overturn concentration. Less resuspension of particulate matter by wind activity at spring overturn in 1981 is believed to be the reason for the reduced phosphorus concentrations.

The loading rate in 1981 using the Dillon and Rigler model was calculated to be 0.19 $g/m^2/yr$ or 1250 kg/yr.

The 1981 loading rate would have to be reduced by 47 percent to mee the permissible loading rate of 0.10 $g/m^2/yr$ which is recommended by Vollenweider (1968). If such a reduction occurs the phosphorus concentrations would be reduced to levels recorded in 1974.

Methods designed to reduce the phosphorus loading rate were discussed at the April 30, 1981 workshop with the trustees of the Dragon Lake Improvement District. A summary of the workshop's recommendations is presented.

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INTRODUCTION

In February, 1980, the Dragon Lake Improvement District asked the Ministry of Environment to study lake water quality. The District was interested in the effects of nutrient loading, and in methods of improving water quality.

This report considers the 1980 water quality, and the sources of nutrients entering the lake. A workshop with the Trustees of the Improvement District was held on April 30, 1981. The purpose of the workshop was to provide technical advice, so the Trustees could implement lake and watershed improvement projects. Various Government agencies attended the workshop and provided information regarding the initiation, design, and implementation of possible projects. The results of the workshop are summarized and incorporated in this report.

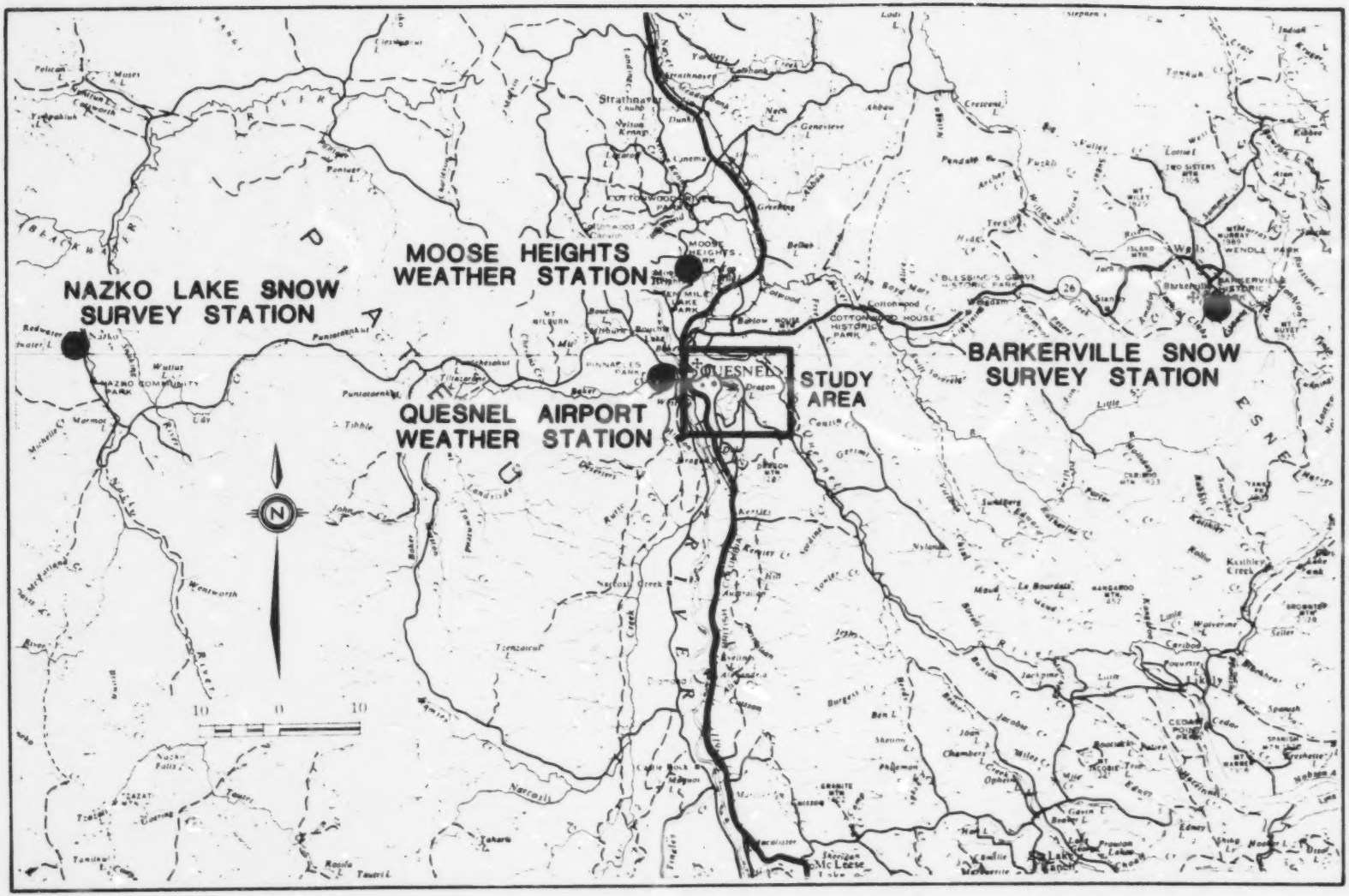


Figure 1 LOCATION OF DRAGON LAKE, SNOW SURVEY STATIONS AND LOCAL WEATHER STATIONS.

METHODS

Water samples were collected by members of the Aquatic Studies Branch and the Trustees of the Dragon Lake Improvement District. Seven stream sites and one lake site were established in 1980. See Figures 1 and 2 for the locations and Table 1 for a description of all monitoring sites. Stream water samples were collected weekly at each site from March 30, 1980 to July 28, 1980. Lake water samples were collected once every three weeks from March 30, 1980 to April 20, 1981. All data are summarized in the report, and permanently stored on the B.C. Ministry of Environment's data storage bank (EQUIS).

A wide range of chemical parameters and biological samples were analyzed at the Ministry of Environment's Environmental Laboratory, Vancouver. Chlorophyll 'a' was measured on June 11 and September 10, 1980. Unconcentrated dip samples were taken on the same dates for quantification of the phytoplankton community.

Temperature profiles were taken every three weeks from March 30, 1980 to April 20, 1981. All temperature measurements were taken with a calibrated YSI 33 conductivity meter.

Dissolved oxygen profiles were taken during late winter when ice still covered the lake, and twice during the summer. All dissolved oxygen measurements were taken with a YSI 57 oxygen meter. Winkler titrations were used to calibrate the oxygen meter on each sampling date.

Secchi disc measurements were taken every three weeks during the study period with a standard 30 cm black and white disc.

Samples for coliform bacteria analysis were sent to the Ministry of Health's Vancouver Laboratory on June 8, 1980.

Various calculations regarding the lake's phosphorus loading or flushing rate occur throughout the report. Formulae, and the basis for the calculations are discussed in the appropriate sections.

GENERAL LAKE CHARACTERISTICS

Dragon Lake is approximately 4 km southeast of Quesnel (Figure 1). It is a shallow, long lake, oriented in the north-south direction. The watershed boundaries for the lake and the inflow creeks are illustrated in Figure 2. Of the three measurable inflows, Dragon Creek is the largest, draining approximately 7.25 km^2. The other two creeks, Holley and Powell, are much smaller with seasonal flows.

A bathymetric map, resulting from a survey by the Fish and Wildlife Branch in 1952, is shown as Figure 3. The lake has a maximum depth of 7 m and an area of 6.4 km^2. Land use within the watershed and the lake's flushing rate are considered in subsequent sections.

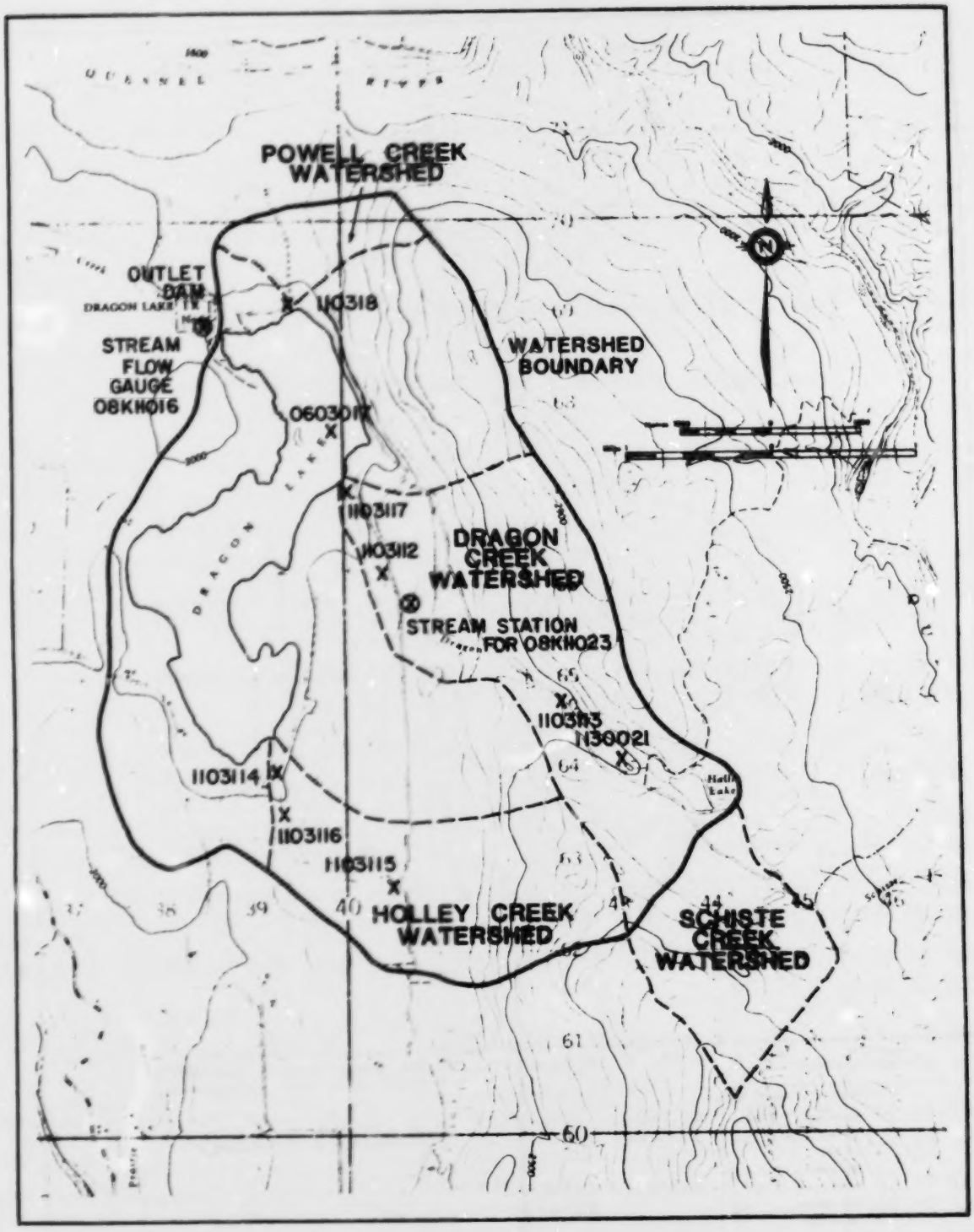


Figure 2 WATERSHED BOUNDARIES, STREAM GAUGE STATIONS AND WATER QUALITY STATIONS FOR DRAGON LAKE.

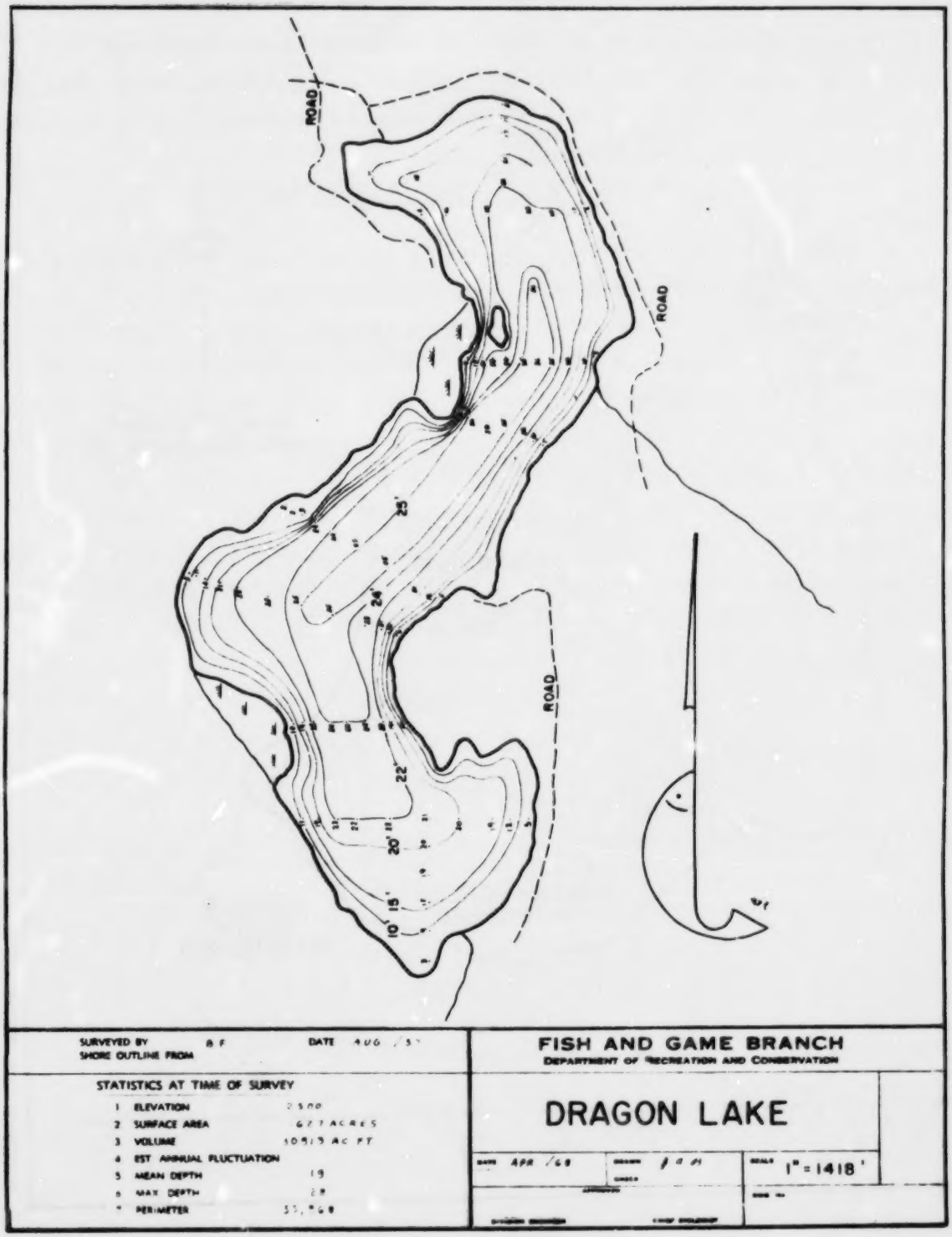


Figure 3 BATHYMETRY AND GENERAL LAKE CHARACTERISTICS FOR DRAGON LAKE.

TABLE 1: Stream, Snow Survey, Weather, and Water Quality Station Descriptions and Locations

Type of Station	General Description	Station Number	Operated by	Years of Operation	Latitude & Longitude
Manual Stream Flow	Dragon Creek at Outlet of Dragon Lake	08KH016	Water Survey of Canada		52 58 14 122 25 36
Manual Stream Flow	Dragon Creek Above Dragon Lake	08KH023	Water Survey of Canada	1971-1980	52 56 37 122 23 44
Snow Survey	Barkerville, B.C.	1A03	B.C. Ministry of Environment	1951-1980	53 03 121 29
Snow Survey	Nazko, B.C.	1C08	B.C. Ministry of Environment	1957-1980	53 01 123 39
Weather	Moose Heights, Quesnel, B.C.		Environment Canada		53 04 122 30
Weather	Quesnel Airport		Environment Canada		53 02 122 31
Water Quality	Dragon Lake at Middle	0603017	Waste Management Branch	1972-active	52 57 30 122 24 30
Water Quality	Dragon Creek at Dragon Lake	1103117	Aquatic Studies Branch	1980-active	52 57 20 122 24 15
Water Quality	Dragon Creek at Dragon Lake Road	1103112	Aquatic Studies Branch	1980-active	52 56 50 122 23 58
Water Quality	Dragon Creek at Hydraulic Road	1103113	Aquatic Studies Branch	1980-active	52 56 02 122 22 15
Water Quality	Holley Creek at Dragon Lake Road	1103114	Aquatic Studies Branch	1980-active	52 55 45 122 25 00
Water Quality	Holley Creek at Feed Lot	1103116	Aquatic Studies Branch	1980-active	52 55 25 122 25 00
Water Quality	Holley Creek at Johnson Road	1103115	Aquatic Studies Branch	1980-active	52 54 58 122 23 50
Water Quality	Powell Creek	1103118	Aquatic Studies Branch	1980-active	52 54 58 122 23 50
Water Quality	Dragon Creek at Hallis Lake	1130021	Aquatic Studies	1981-active	52 55 30

WATER LICENCES

As of January 1981 there were 49 domestic and 11 industrial or irrigation water licences on the lake. On Dragon Creek and tributaries there were 14 domestic and 5 irrigation licences. Other licences within the watershed included two water storage and two land improvement licences. All water licences within the watershed are summarized in Table 4, listed in Appendix 1, and illustrated in Figure 4 (fold out map in back cover).

Removing lake water for irrigation or domestic purposes, reduces the amount of water flowing out of the lake. The removal however does not reduce the lake's flushing rate.

Calculation of the lake's outflow volume must include the water removed for domestic and irrigation purposes. The volumes of water removed rarely approached the volumes permitted under the water licence. Consequently the volume of water withdrawn by all licences was estimated to be 80 percent of the total licenced volume. Table 4 summarizes the annual domestic and irrigation volumes utilized from 1972-1980. Most of the water removed will be lost to evaporation or evapotranspiration, but some will return to the lake. The proportion of water that returns to the lake is not considered withdrawn, and must be subtracted from the total volume of water utilized. The portions of irrigation and domestic water which returned to the lake were estimated to be 20 and 60 percent, respectively, of the water initially withdrawn (Wiens, pers. comm.). The volumes of water annually removed from the watershed are listed in Tables 2 and 3, and incorporated in the flushing rate calculations on page 11.

TABLE 2: Annual Water Utilization and Water Loss from Dragon Lake

Year	Volume of Water Licenced for Irrigation Per Year (dam^3)*	Esti-mated Percent of Licenced Volume Utilized	% Lost	Volume of Irrigation Water Lost Per Year (dam^3)	Volume of Water Licenced for Domestic Purposes Per Year (dam^3)*	Esti-mated Percent of Licenced Volume Utilized	% Lost	Volume of Domestic Water Lost Per Year (dam^3)
1972	330	80	80	210	46.5	80	40	14.9
1973	330	80	80	210	87.9	80	40	28.1
1974	330	80	80	210	144.7	80	40	46.3
1975	330	80	80	210	180.9	80	40	57.9
1976	330	80	80	210	217.1	80	40	69.5
1977	330	80	80	210	232.6	80	40	74.4
1978	330	80	80	210	237.7	80	40	76.1
1979	330	80	80	210	242.9	80	40	77.7
1980	330	80	80	210	253.2	80	40	81.0

* Volumes calculated from Appendix 1, in cubic decametres.

Removal of water from Dragon Creek, or its tributaries, reduces the volume of water entering the lake. In 1980, 298 cubic decametres (dam^3) was licenced for use from the creeks. An estimated 80 percent of the licenced water (238 dam^3) was utilized. Using the same evaporation and evapotranspiration estimates used for domestic and irrigation purposes (as in Table 2), an estimated 165 dam^3 of the water withdrawn did not reach Dragon Lake. This withdrawal reduced the lake's flushing rate. The impact of the withdrawal on the flushing rate is discussed on page 16.

TABLE 3: Annual Water Utilization and Water Loss from the Dragon Lake Inflow Streams

Year	Volume of Water Licenced for Irrigation (dam^3)*	Estimated Percent of Licenced Volume Utilized	Percent Lost	Volume of Irrigation Water Lost (dam^3)	Volume of Water Licenced for Domestic Purposes* (dam^3)	Estimated Percent of Licenced Volume Utilized	Percent Lost	Volume of Domestic Water Lost (dam^3)
1972	206	80	80	132	72	80	40	23
1973	206	80	80	132	72	80	40	23
1974	206	80	80	132	72	80	40	23
1975	206	80	80	132	72	80	40	23
1976	206	80	80	132	78	80	40	25
1977	206	80	80	132	78	80	40	25
1978	206	80	80	132	78	80	40	25
1979	206	80	80	132	78	80	40	25
1980	212	80	80	136	86	80	40	28

* Volumes calculated from Appendix 1.

TABLE 4: Summary of the Water Licences* Within the Dragon Lake Watershed

Licence Location	Type of Licence	Number of Licences	Total Volume of Water Licenced (dam^3/yr)	Appendix
Dragon Lake	Domestic	49	253	1a
	Irrigation or Industrial	11	334	1b
	Land Improvement	1	N/A	1b
Dragon Creek	Domestic	6	47	1c
	Irrigation	4	96	1d
	Storage	2	111	1d
Dragon Creek Tributaries	Domestic	9	80	1e
	Irrigation	1	11	1e
	Land Improvement	1	N/A	1e

* All licences are individually listed in Appendix 1.

WATER BALANCE

Water flow data are available for the watershed from stream gauges situated at the outlet of the lake, and on Dragon Creek 1.75 km upstream from the lake (Figure 2). Annual stream flows at the two stations are summarized in Table 5, and the hydrological cycle for the stream flow station above the lake is illustrated in Figure 5.

Average annual precipitation was calculated from 38 years of data (1941-1979) recorded at the Quesnel Airport weather station. The mean monthly and 1979-1980 monthly precipitation data are listed in Table 6. Table 7 lists the annual precipitation for 1972-1980.

Precipitation in 1973 and 1978 approximated closely the average annual precipitation. Below normal snow pack volumes in 1978 produced below average watershed runoff (Table 7). Consequently, the flushing rate for an average precipitation year was calculated from the 1973 water flow data (Table 5).

In order to calculate accurately the lake's outflow volume, the amount of water withdrawn from the watershed for domestic and irrigation purposes must be included. Irrigation and domestic utilization in 1980 may have removed as much as 330 and 253 dam^3 respectively (Table 2). Some of the water removed will have returned as groundwater, but a significant percentage will have been lost from the watershed. The true flushing rate will be based on the volume of water measured at the outflow plus the calculated annual water loss from the lake (Table 2).

TABLE 5: Annual Stream Flows for Both Stream Stations

Year	Discharge Volume at Dragon Cr. at Outlet of Dragon Lake 08KH016 (dam^3)*	Estimated Loss from Water Utilization[1] (dam^3)		Corrected Outflow (dam^3)	Watershed Runoff Ratio Above 08KH016 (dam^3/ha)	Discharge Volume at Dragon Cr. Above Dragon Lake 08KH023 (dam^3)	Watershed Runoff Ratio Above 08KH023 (dam^3/ha)	Dragon Cr. Volume at 08KH023 as a Percent of the Outflow Volume
		Irrigation	Domestic					
1972	incomplete	210	15	incomplete	-	1650	2.3	-
1973	1961	210	28	2200	0.52	862	1.2	44
1974	4156	210	46	4412	1.04	1840	2.5	44
1975	incomplete	210	58	incomplete	-	605	0.8	-
1976	incomplete	210	70	incomplete	-	1550	2.1	-
1977	1520	210	74	1804	0.43	966	1.3	64
1978	1680	210	78	1971	0.47	655	0.9	39
1979	incomplete	210	81	incomplete	-	744	1.0	-
1980	0	210	81	0	0	482	0.7	N/A

* 1.2335 cubic decametres equals 1 acre foot.

[1] From Table 2.

TABLE 6: 1980 and Mean Monthly Stream Flow, Precipitation and Evaporation Data for the Dragon Lake Watershed

MONTH	Average Monthly Stream Volumes (dam^3/month)		Minimum Recorded Volume (dam^3/month)	Year Minimum Volume Recorded	1980 Monthly Volumes (dam^3)		Mean Monthly Precipitation (mm) Quesnel Airport 1941-1970	Estimated Evaporation Rates at Quesnel Airport (mm) (Wilson, 1977)	Net Evaporation (Precipitation - Evaporation) (mm)
	Station 08KH016	Station 08KH023			Station 08KH016*	Station 08KH023			
January	16.1	17.5	8.7	1979	0	11.6	56.4	-	+56.4
February	2.4	22.1	8.1	1979	0	10.1	36.1	-	+36.1
March	49.2	122.5	12.6	1975	0	24.4	25.9	24.2	+ 1.7
April	1226	502.1	64.1	1980	0	64.1	24.4	63.9	-39.5
May	814	207.9	38.4	1980	0	38.4	35.8	115.3	-79.5
June	85.5	99.8	24.9	1980	0	24.9	56.6	147.3	-90.7
July	180	43.0	16.4	1978	0	31.4	54.1	155.0	-100.9
August	37.5	21.0	5.3	1974	0	24.9	71.1	120.0	-48.9
September	23.3	12.8	2.6	1974	0	31.4	41.7	57.6	-15.9
October	34.8	18.3	6.9	1974	0	44.3	47.2	15.8	+31.4
November	46.7	21.5	8.2	1979	0	52	45.5	-	+45.5
December	72.3	20.9	9.2	1979	0	115	46.5	-	+46.5
TOTAL	2587.8	1109	465.9		0	482.4	541.3	699.1	-158.1

Net Summer Evaporation Loss = 375.4 mm

* Based on records kept by the Dragon Lake Improvement District.

TABLE 7: Annual Precipitation Data for Weather and Snow Survey Stations Around the Dragon Lake Watershed

Year	Annual Precipitation at Quesnel Airport (mm)	Precipitation as a Percent of the 38 Year Average	Precipitation at Moose Heights, Quesnel (mm)	Snow Pack as a Percent of the Average, at the Closest Snow Survey Stations*	
				Bakerville	Nazko Lk.
1972	603.8	112	664.0	125	125
1973	481.6	89	467.1	95	137
1974	479.6	89	471.9	124	196
1975	577.1	107	597.4	96	186
1976	620.5	115	639.6	107	208
1977	526.9	98	557.6	72	0
1978	473.0	88	538.9	62	64
1979	459.1	85	488.9	92	22
1980	683.2	126	-	63	28
1972-1979 avg.	427.7		553.2		
1941-1970 avg.	541.3		not available		
38 year avg.	538.4		not available		

* From B.C. Ministry of Environment Snow Bulletin.

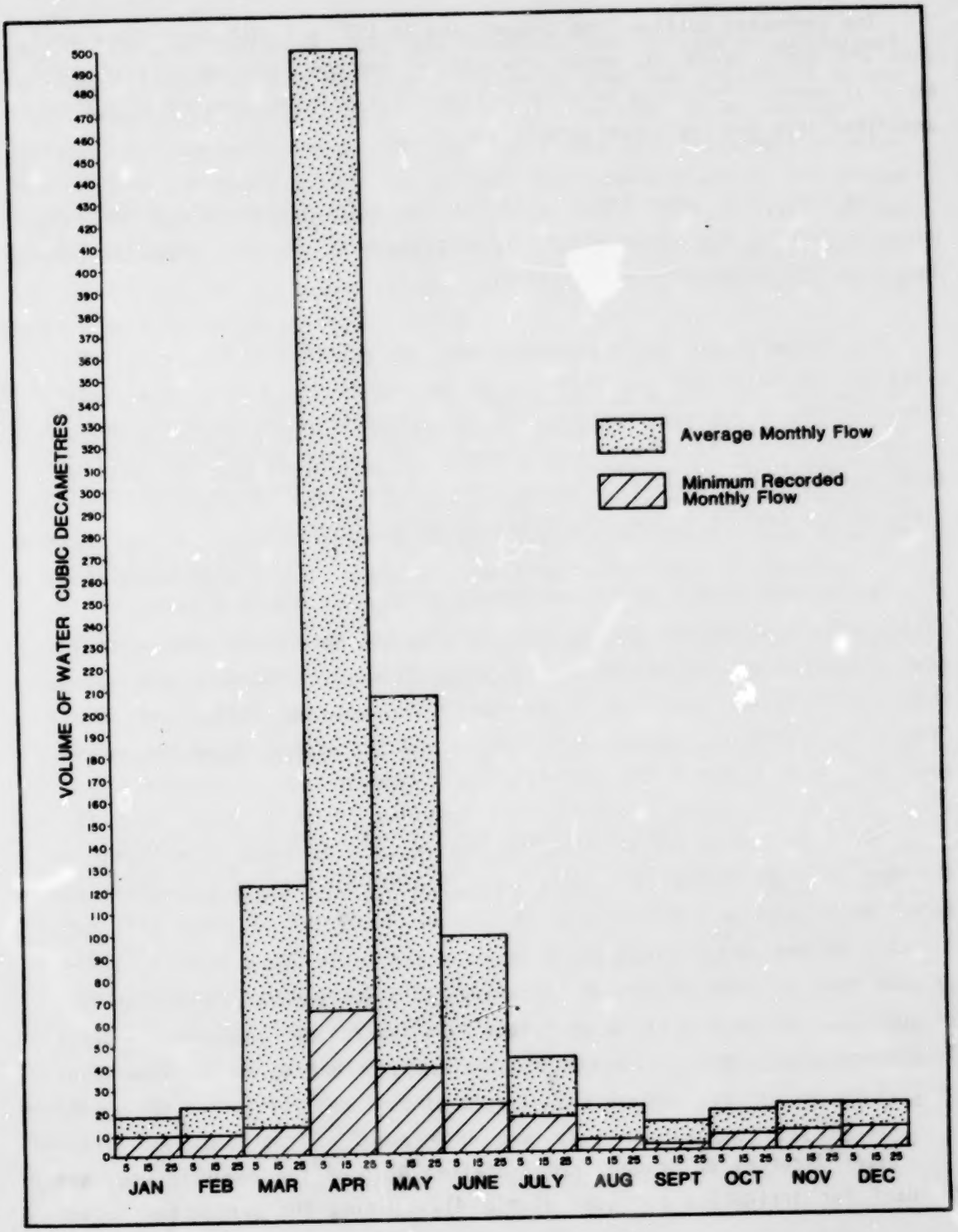


Figure 5 HYDROLOGICAL FLOW PATTERN FOR DRAGON CREEK IN AN AVERAGE AND MINIMUM PRECIPITATION YEAR.

The corrected outflow from Dragon Lake in 1973 was 2200 dam^3 (1960 dam^3 plus 240 dam^3; Table 5), which produces an average flushing rate of once every 17 years. This is a relatively slow flushing rate, created by a small watershed area and low annual precipitation.

The removal of water from the inflow creeks for irrigation and domestic purposes reduces the inflow volume by approximately 155 dam^3 annually. The impact on the flushing rate is minimal.

The inflow creeks and their watersheds are outlined in Figure 2. Dragon Creek is the major inflow, draining 17 percent of the lake's total watershed. During an average precipitation year it contributes about 860 dam^3 or 39 percent of the total watershed runoff. The water runoff ratio for the creek averaged 1.5 dam^3/ha, ranging from 2.3 dam^3/ha in high precipitation years to 0.8 dam^3/ha in low precipitation years (Table 5).

Holley and Powell Creek watersheds occupy 13 and 5 percent of the lake's watershed respectively. Because the two watersheds are below the mean elevation of the Dragon Creek stream flow gauge 08KH023, the watershed runoff ratios are less. The runoff volumes for Holley and Powell Creeks are estimated, respectively, at 50 and 20 percent below the corresponding flow on Dragon Creek (Reksten, pers. comm.).

Direct precipitation of water on Dragon Lake is quite significant as the surface area of the lake represents 15 percent of the total watershed. Based on an average precipitation of 538 mm, 3450 dam^3 of water will fall directly on the lake. Evaporation is estimated to be 700 m (Wilson, 1977), or 4480 dam^3 per year (Table 6). This creates a net annual evaporation loss of 1030 dam^3, or a drop of 16 cm in the lake level. Net summer evaporation losses are much higher, estimated at 2500 dam^3, or a drop in the lake level of 37.5 cm.

Water licences on Dragon Creek totalled 47 dam^3 for domestic use, and 96 dam^3 for irrigation per year (Table 4). During the irrigation season

(May 1 through September 30), the domestic and irrigation withdrawal totalled 135 dam^3 or 0.88 dam^3/day*. Spawning trout are present in Dragon Creek from April through June. In early June the flows average 3.3 dam^3/day, but can be as low as 0.83 dam^3/day (Table 6). The amount of water removed from the creek during the periods when spawners are in the stream can be as much as 50 percent of the total flow. The survival of the spawners depends on adequate flows in the creek in June and July. Rainbow fry are present in the creek in July and August. Low flows during these months can also affect survival.

Establishing a minimum flow in Dragon Creek to ensure the survival of the adult spawners and the fry is recommended as a top priority of the Dragon Lake Improvement District. Release of stored water to augment the low flows is the best method of preventing flows from dropping below the desired levels. For the purpose of this report the desired creek flows in June, July and August will be the average flow rates listed in Table 6.

Estimation of storage requirements in the upper portions of Dragon Creek is based on the following assumptions.

1) No further utilization of Dragon Creek for domestic or irrigation purposes.
2) The amount of water released from storage facilities will not be diverted from the creek for any other purposes.
3) The amount of water stored will be sufficient to raise the minimum flows in June, July and August to the average flows listed in Table 6.

The minimum recorded flows in June, July and August were 0.83 dam^3/day*, 0.54 dam^3/day, and 0.17 dam^3/day respectively. The average flows for the same time periods were 3.3 dam^3/day, 1.39 dam^3/day and 0.68 dam^3/day. Release rates required to elevate the minimum flow to the average flow are 2.47 dam^3/day in June, 0.85 dam^3/day in July and 0.51 dam^3/day in August.

*to convert to cfs, divide by 2.45.

A head of 1.2 metres of stored water on Hallis Lake could supply the calculated 115 dam^3 of water needed for release in June, July and August.

Runoff from 3 km^2 of the upper Schiste Creek watershed (Figure 2) could be diverted into Dragon Creek to increase the lake's flushing rate. Using a watershed runoff ratio of 2 dam^3/ha, only 600 dam^3 of water could be diverted in an average precipitation year. The flushing rate could be reduced from 17 to 13.5 years.

The benefits of the project would be:

1) increased summer stream flows in Dragon Creek.
2) a small increase in the flushing rate which could result in a slight improvement in the water quality (discussed further on page 29).
3) an additional 6,000 kg of silica would be added to the lake (discussed further on page 28).

The Schiste Creek diversion is not considered significant in the rehabilitation of the water quality of the lake. This is discussed further on page 29.

WATER QUALITY OF THE LAKE

TEMPERATURE

Temperature profiles taken in 1980 are summarized in Figure 6. Because of the lake's shallowness (7 m maximum), a strong thermal gradient (thermocline) did not develop. The absence of a thermocline allows wind to mix the surface and bottom waters. Consequently, the temperatures at the surface and bottom of the lake were similar. At the lake's centre, the maximum summer temperatures were 20.5°C at the surface and 19°C at 7 m (Figure 6).

The presence of ice prevents the surface water from being mixed by the wind during the winter. This allows the water column to become thermally stratified. Typically, water is at maximum density at 4°C, and will settle at the bottom of the lake. The surface water is cooler and less dense, approaching 0°C at the ice-water interface.

DISSOLVED OXYGEN

Dissolved oxygen concentrations were measured three times in 1980 (Figure 7). A common problem in eutrophic lakes is deoxygenation of the bottom water through the bacterial utilization of oxygen during decomposition of organic materials. Because Dragon Lake does not have a strong summer thermocline, wind is able to mix the surface and bottom waters thereby replenishing the oxygen consumed by bacteria. Consequently, the bottom waters are well oxygenated throughout the entire summer. During the winter months ice prevents wind mixing, and the bottom two metres become anoxic (Figure 7).

BIOCHEMICAL OXYGEN DEMAND

The biochemical oxygen demand in Dragon Lake was high, averaging 26 ± 6.0 mg/L (n=3) under the ice in March, and 27 mg/L (s.d.=0; n=3) in September. In the winter of 1979-1980 the oxygen demand produced anoxic conditions below four metres. The winter oxygen demand was not sufficient to create a fish kill situation. However, future increases in lake

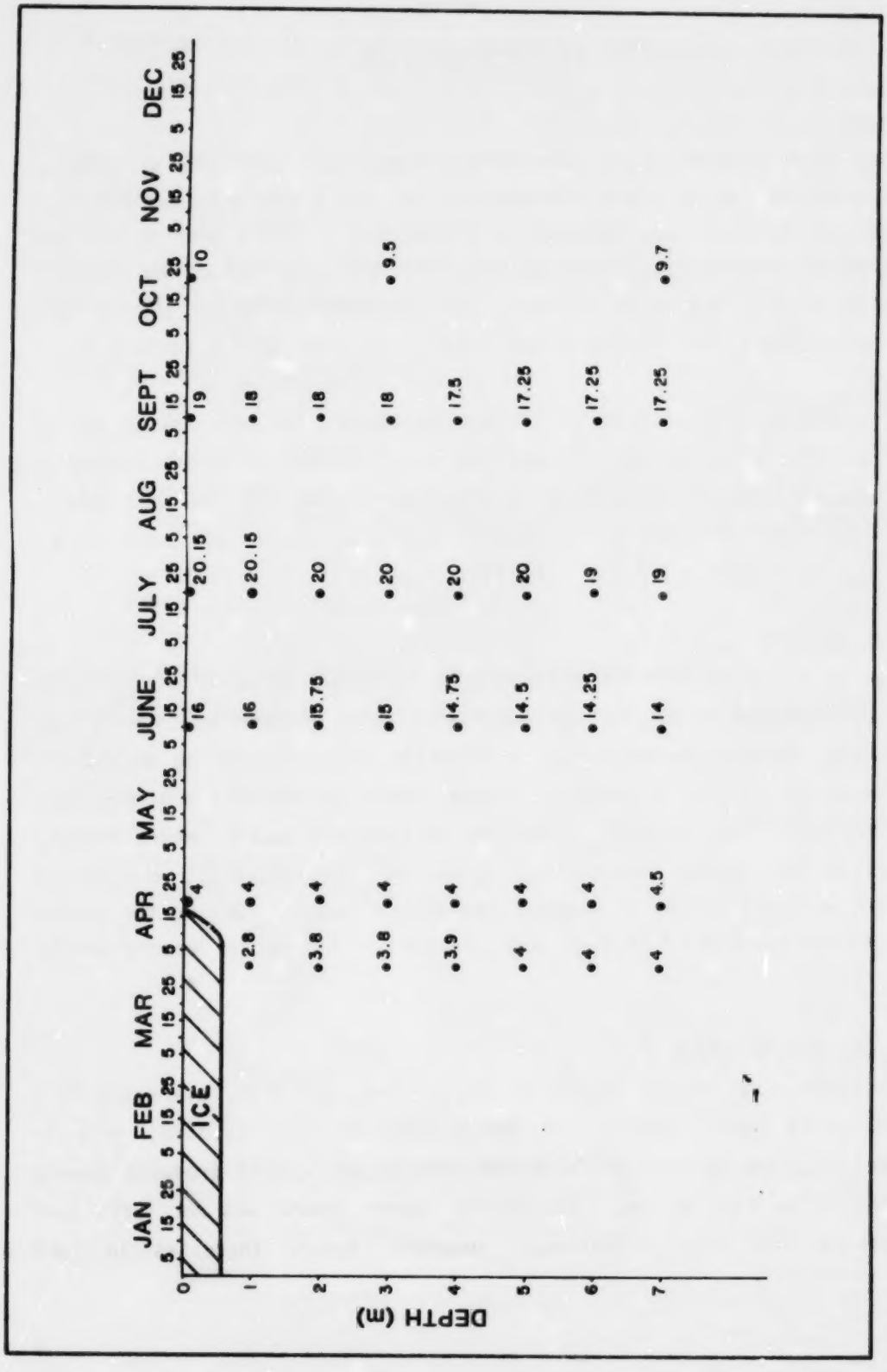


Figure 6 TEMPERATURE (°C) AS A FUNCTION OF TIME AND DEPTH FOR THE CENTER OF DRAGON LAKE IN 1980. SITE 0603017.

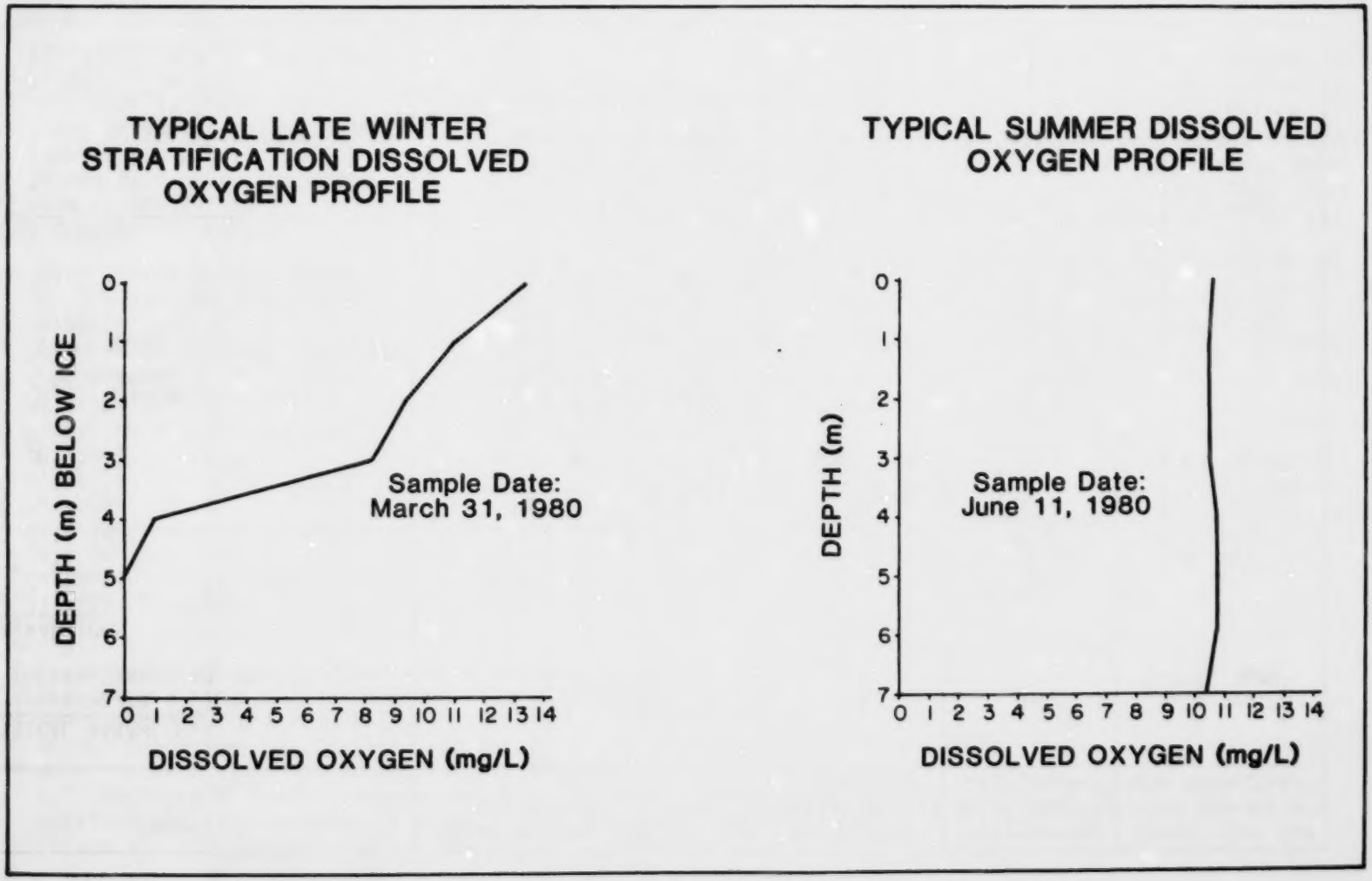

TYPICAL LATE WINTER STRATIFICATION DISSOLVED OXYGEN PROFILE
DEPTH (m) BELOW ICE
0 1 2 3 4 5 6 7
Sample Date:
March 31, 1980
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
DISSOLVED OXYGEN (mg/L)
TYPICAL SUMMER DISSOLVED OXYGEN PROFILE
DEPTH (m)
0 1 2 3 4 5 6 7
Sample Date:
June 11, 1980
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
DISSOLVED OXYGEN (mg/L)

Figure 7 TYPICAL LATE WINTER AND SUMMER DISSOLVED OXYGEN PROFILES FOR DRAGON LAKE.

TABLE 8: Summary of the 1980 Dragon Lake Water Quality Data and the Recommended Water Quality Standards and Objectives for Domestic Drinking Water

Parameter	Water Quality Results for Dragon Lake in 1980	Recommended Water Quality Standards	Recommended Water Quality Objectives	Agency that Set the Standards and Objectives
PHYSICAL PARAMETERS				
1) Temperature (°C)	20.15[b] (max)	15	10	B.C. Health
2) Oxygen-Dissolved (mg/L)	6.1 (min)	3	-	SSPAC[c], WQMO[d]
GENERAL IONS				
1) Alkalinity (mg/L)	125 ± 19 (n = 17)	-	-	-
2) Carbon-Inorganic (mg/L)	31.8 ± 4.7 (n = 25)	-	-	-
3) Calcium-Total (mg/L)	32.3 ± 3.0 (n = 15)	200	**<75	B.C. Health
4) Chloride - Dissolved (mg/L)	2.6 ± 0.8 (n = 8)	250	<250	B.C. Health
5) Hardness (mg/L)	140[a] ± 22 (n = 17)	180	120	B.C. Health
6) Magnesium-Dissolved (mg/L)	15.2 ± 0.7 (n = 16)	150	<50	B.C. Health
7) pH (Relative Units)	8.3 ± 0.2 (n = 27)	6.5 - 8.5	-	B.C. Health
8) Potassium - Dissolved (mg/L)	3.0 ± 0.6 (n = 8)	-	-	-
9) Silicate (mg/L)	1.6 ± 0.9 (n = 23)	-	-	-
10) Sodium (mg/L)	5.4 ± 1.2 (n = 7)	-	-	-
11) Specific Conductance (umho/cm)	298 ± 44 (n = 34)	-	-	-
12) Sulphate (mg/L)	21.4 ± 4.4 (n = 10)	500	250	B.C. Health
13) Total Dissolved Solids (mg/L)	182 ± 22 (n = 26)	1000	<500	B.C. Health
14) Total Inorganic Solids (mg/L)	111 ± 19 (n - 25)	-	-	-
WATER CLARITY AND COLOUR				
1) True Colour (T.C.U.)	7.1[a] ± 5.5 (n = 26)	15	<5	B.C. Health
2) Secchi Disc Depth (metres)	4.8 ± 1.7 (n = 4)	-	-	-
3) Tannins and Lignins (mg/L)	0.2 ± 0.1 (n = 10)	-	-	-
4) Total Suspended Solids (mg/L)	184 ± 22 (n = 26)	-	-	-
5) Turbidity (N.T.U.)	1.3[a]± 0.6 (n = 26)	5.0	<1.0	B.C. Health
Turbidity (N.T.U.)	2.8[a] (max)	5.0	<1.0	B.C. Health
Turbidity (N.T.U.)	0.6 (min)	5.0	<1.0	B.C. Health

TABLE 8 (cont'd)

Parameter	Water Quality Results for Dragon Lake in 1980	Recommended Water Quality Standards	Recommended Water Quality Objectives	Agency that Set the Standards and Objectives
NUTRIENTS				
1) Nitrogen-Ammonia (mg/L)	0.09[a] ± 0.04 (n = 25)	0.5	<0.01	B.C. Health
2) Nitrogen-Nitrate (mg/L)	0.046 ± 0.05 (n = 25)	10	<10	WQC[e]
3) Nitrogen-Total (mg/L)	0.9 ± 0.18 (n = 26)	-	-	-
4) Phosphorus-Ortho (mg/L)	0.008 ± 0.009 (n = 26)	0.065	0.065	B.C. Health
5) Phosphorus-Total (mg/L)	0.033 ± 0.011 (n = 24)	-	-	-
6) Carbon-Organic (mg/L)	8.2 2.5 (n = 25)	-	-	-
BACTERIA				
1) Coliforms-Faecal (M.P.N.)	1[b] ± 0 (n = 6)	0[f]	-	B.C. Health
2) Coliforms-Total (M.P.N..)	2[a] 2 (n = 6)	0	-	B.C. Health

* Standard Deviation
** < denotes 'less than'

NOTES:
a Parameter exceeds the recommended water quality objective.
b Parameter exceeds the recommended water quality standard.
c SSPA: Scientific Stream Pollution Analysis, Nemerow, 1974.
d WOMO: Guidelines and Criteria for Water Quality Management in Ontario, 1979
e WQC: Water Quality Criteria. E.P.A., 1972.
f B.C. Ministry of Health recommended drinking water standard requires 'Most Probable Number' (M.P.N.) of coliform bacteria to be 0 cells/100 ml for untreated drinking water, and 50 faecal coliforms/100 ml for 'Class A' water (prior to disinfection).

productivity may increase the oxygen demand to the point where winter kills may occur.

SUITABILITY FOR DOMESTIC DRINKING WATER

Summer water temperatures and coliform bacteria concentrations were the only parameters to exceed the B.C. Ministry of Health recommended water quality standards for drinking water (Table 8).

The coliform concentrations at Dragon Lake were usually undetectable. The occasional presence of faecal coliform bacteria caused the water to exceed the recommended standards for raw drinking water.

Water hardness, colour, turbidity and ammonia were the only parameters to exceed the water quality objectives recommended for drinking water (Table 8). They were, however, well within the recommended drinking water standards. In general, the water quality of Dragon Lake for domestic purposes is good, but a purification method that would remove occasional coliform bacteria is advisable.

TASTE AND ODOURS

Taste and odours in domestic drinking water can be caused by organic compounds excreted by algae. Chara, a rooted macroalga common in Dragon Lake can impart a skunk, or spoiled odour in the water (Palmer, 1962).

TABLE 9: Dominant Phytoplankton Species in Dragon Lake in 1980

Sampling Date	Dominant Species*	Algal Group	Cells Per ml
June 11, 1980	Chroomonas	flagellate	158
	Microcystis incerta	blue green	119
	Anabaena flos-aquae	blue green	100
	Coelosphaerium naegelianum	blue green	45
	Diatom species	diatom	0.15
September 10, 1980	Microcystis aeruginosa	blue green	32,660
	Anabaena flos-aquae	blue green	4,660

* Samples identified by Environmental Laboratory, Ministry of Environment.

There are several species of blue green algae observed in Dragon Lake (Table 9). None of the phytoplankton recorded in Dragon Lake are known to have caused taste or odours in other drinking water supplies, according to Palmer (1962).

NUTRIENTS

Floating or attached aquatic plants in every aquatic ecosystem require light and nutrients in order to grow. During the spring and summer months the availability of nitrogen and phosphorus is the main factor that limits the growth rate of aquatic plants. Sunlight does not limit plant growth until the late fall and winter, when the photoperiod is short and the intensity of the sunlight is low. Another factor limiting the action of sunlight is turbid water, or water containing dissolved or suspended matter that absorbs the photosynthetically active wavelengths of light. Dissolved humic materials, which impart a strong brown colour, can significantly limit sunlight intensity for plants.

TABLE 10: Nitrogen and Phosphorus Concentrations, Ratios, and Mass for Dragon Lake at Station 0603017

Date	Total Nitrogen Concentration In Dragon Lake (mg/L)	Total Phosphorus Concentration In Dragon Lake (mg/L)	N/P Weight Ratio	Nitrogen Mass in Lake (kg)	Phosphorus Mass in Lake (kg)
73 10 02	1.14	0.008	142:1	43 600	305
74 08 20	0.53	0.009	59:1	20 300	345
80 03 31	1.03	0.039	26:1	39 400	1500
80 04 19	0.91	0.039	23:1	34 800	1500
80 05 04	0.78	0.025	31:1	29 900	955
80 06 08	0.64	0.025	25:1	24 500	955
80 07 20	0.98	0.031	32:1	37 500	1185
80 08 19	0.90	0.022	42:1	34 500	840
80 09 10	0.95	0.041	23:1	36 400	1570
80 10 21	1.04	0.042	23:1	39 800	1605

Large rooted aquatic plants such as Nuphar (lily pad) obtain the majority of required nutrients from the sediments (Tilley et al., 1977), whereas Myriophyllum (a common large plant in Dragon Lake) will obtain the nutrients from both the sediments and the water (Bole and Allan, 1978). Phytoplankton, a term used to describe the small planktonic algae, obtain nutrients exclusively from the aquatic medium (Wetzel, 1975).

The nitrogen:phosphorus weight ratio required by all aquatic plants for growth is considered to be between 5:1 and 15:1 (Schindler, 1974). Consequently, for conditions where the weight ratio is less than 5:1, nitrogen is considered to be the limiting factor. Conversely, if the weight ratio exceeds 15:1, phosphorus is considered to be the limiting factor. The nitrogen:phosphorus weight ratios for Dragon Lake in 1980 (Table 10) show that the growth of planktonic algae was theoretically limited by the availability of phosphorus throughout the entire summer and fall.

The 1980 spring overturn phosphorus concentration was 39 µg/L which classifies the lake as eutrophic according to Vollenweider (1968). Sakamoto (1966), Dillon and Rigler (1975), Nordin (in prep.) and others have established a direct positive relationship between spring overturn phosphorus concentration, and the mean summer chlorophyll 'a' concentration (a measure of the phytoplankton biomass). The mean chlorophyll 'a' concentration predicted from the model developed for B.C. lakes (Nordin, in prep.) was 8.9 µg/L. Two chlorophyll samples collected in June and September 1980 were <0.5 µg/L and 1.5 µg/L respectively. The low values indicate that the phytoplankton biomass was far below the theoretical levels predicted by the models. This generalization is supported by the Secchi disc values (a relative measure of water clarity) which averaged 4.8 ± 1.7 m. These values are indicative of a lake with a low phytoplankton biomass.

The low phytoplankton biomass suggests that physical, chemical or biological factors, other than the availability of phosphorus, were restricting the growth of the phytoplankton community. Intense zooplankton predation of algae could be the reason for the low biomass levels observed in 1980. More intensive sampling and analysis in the future may provide more information regarding this hypothesis.

The 1981 spring overturn phosphorus concentration was 22 µg/L, which is 44 percent below the 1980 concentration. The reduction was caused by reduced wind activity during spring overturn. The influence of wind induced circulation on the phosphorus concentrations is discussed further on page 34.

In the past few years, local residents have noticed an increase in rooted aquatic plants, and algae that form floating mats. Increased nutrient concentrations must be contributing to the increased growth of these aquatic plants.

One consequence of the increased phytoplankton growth has been a depression in the lake's reactive silica concentration. At spring overturn the reactive silica concentration was undetectable, but it increased throughout the summer to a maximum concentration of 2.1 mg/L. The 1980 reactive silica values are approximately one half the 1973 and 1974 values for the same time period.

The low levels of reactive silica and the elevated phosphorus concentrations create conditions suitable for the growth of blue-green algae rather than more desirable diatom species. Analysis of the plankton community on June 8 and September 10, 1980, showed that the dominant phytoplankton species were blue-green algae, and diatom concentrations were very low (Table 9). The presence of a muddy taste in the fish caught during the summer can be attributed to the presence of blue green algae (Lovell and Slackey, 1973; and Tabachek and Yurkowski, 1976). Alteration of the reactive silica and phosphorus concentrations will promote growth of the diatom community.

Dissolved silica could be added to the lake and can be purchased in a commercial form. The silica concentrate could be easily applied on the ice during the winter with the use of a tractor and boom sprayer. Application rate of the compound, which is 28.7 percent silicon dioxide by weight, would be 140 lbs/acre (157 kg/ha). This application rate would raise the spring overturn reactive silica concentration to approximately 5 mg/L. The cost,

however, restricts the practicality of such a project, for 370 drums (45 gallon) would be required per year at a cost of $82.50 per drum or a total of about $30,000.

Addition of 600 dam^3 of water from the Schiste Creek watershed in an average precipitation year (discussed on page 18), would contribute approximately 6000 kg of silica annually to the lake. The input, however, would increase the 1980 spring overturn silica concentration by an estimated 15 percent. This would probably not have any measurable effect on stimulating growth of the diatom community.

Phosphorus concentrations in Dragon Lake have increased dramatically in the past several years. Samples taken in 1980 show concentrations at least 2-3 times greater than the phosphorus concentrations for the same period in 1973 and 1974 (Table 10). Nitrogen concentrations over the same time period did not increase as dramatically, but Table 10 shows the nitrogen:phosphorus weight ratio in 1980 is still greater than 15:1. Theoretically this would indicate that phosphorus was the factor limiting the summer growth of planktonic algae.

Using the spring overturn concentration and several morphometric parameters, the amount of phosphorus added to the lake each year can be calculated by the models presented in Table 11. Unfortunately, the results of calculations using the models do not agree well because the models are not well suited for shallow, unstratified lakes with slow flushing rates.

TABLE 11: Summary of the Phosphorus Loading Models used for Dragon Lake in 1980

Model Number	Author	Year Published	Equation	Calculated Loading Rate In 1980 (L) ($g/m^2/yr$)	Calculated Loading in 1980 (kg/yr)
1	Reckhow and Simpson	1980	$L = P\ (11.6 + 1.2q_s)$	0.48	3155
2	Dillon and Rigler	1975	$L = \frac{(P \times q_s)}{(1 - R_{kd})}$	0.34(1980) 0.19(1981)	2235(1980) 1250(1981)

FORMULA ABBREVIATIONS

P = spring overturn phosphorus concentration (mg/L)

L = loading rate ($g/m^2/yr$)
q_s = surface overflow rate (m/yr)

$q_s = z/\tau$
1980 q_s = 0.345 m/yr

z = lake mean depth

τ = hydraulic detention time (yr)

Q = annual volume rate of water inflow to lake (10^6 m^3/yr) for Dragon Lake in 1980
$Q = 22 \times 10^6 m^3$

R_{kd} = phosphorus retention factor as calculated by Kirchner and Dillon (1975) = 0.9601

A = Lake Area: 6.4 km^2

Z = Mean Depth: 6 metres

The Dillon and Rigler model was used to predict the reduction in phosphorus concentration at spring overturn following increases in the flushing rate. The portion of the Schiste Creek watershed available for diversion into the Dragon Creek watershed would yield an estimated 600 dam^3 in an average precipitation year (see page 18). If the diversion were implemented, the flushing rate would be reduced from 17 years to 13.5 years. Provided the increased flow in Dragon Creek did not transport more phosphorus to the lake (i.e., the present stream loading rate remained the same), only a marginal reduction in the spring overturn phosphorus concentration would result.

Table 12 lists the calculated spring overturn phosphorus concentration as a function of the flushing rate. Both q_s and R_{kd} (Table 11) are a function of flushing rate, and hence will change accordingly. Using the phosphorus loading rate of 0.1902 $g/m^2/yr$ (which is the 1981 loading rate that is not influenced by wind activity), the phosphorus concentration at spring overturn does not change dramatically until the flushing rate approaches a value of once per year.

Table 12: Calculation of Spring Overturn Phosphorus Concentration as a Function of Flushing Rate, using the Dillon and Rigler (1975) Model

Flushing Rate (years)	Surface Overflow Rate: q_s (m/yr)	Phosphorus Retention Factor: R_{kd} From Kirchner and Dillon (1975)	Spring Overturn Phosphorus Concentration Calculated From The Dillon And Rigler (1975) Model* (µg/L)
17.0	0.345	0.9601	22.0
13.5	0.444	0.9493	21.7
10.0	0.600	0.9328	21.3
7.5	0.800	0.9126	20.8
5.0	1.200	0.8752	19.8
2.5	2.400	0.7834	17.2
1.0	6.000	0.6260	11.9
0.5	12.000	0.5286	7.5

* Annual phosphorus loading rate at 0.1902 $g/m^2/yr$.

These calculations show that any decrease in spring overturn phosphorus concentration can only occur when the flushing rate approaches once per year.

NON-POINT PHOSPHORUS SOURCES

STREAMS

Detailed sampling in 1980 revealed that stream loading added approximately 130 kg of phosphorus to the lake. Even though the 1980 stream concentrations were high, the stream flows during freshet were sufficiently low to reduce the impact of nutrient sources (primarily farming) on the nutrient concentrations of the lake. The stream sampling stations were not affected by livestock immediately around the lake. Direct nutrient input from livestock is accounted for in a later section.

Phosphorus loadings were calculated by multiplying the weekly stream flow by the nutrient concentration determined for that time period. Table 13 lists the weekly phosphorus loading rates for Dragon Creek.

TABLE 13: Calculation of Phosphorus Loading from Dragon Creek in 1980

Time Period	Flow For Dragon Creek 08KH023 (litres/week)	Creek Phosphorus Concentration (mg/L)	Phosphorus Loading To Dragon Lake (kg/week)
March 1 - April 6	350 x 10^6	0.100	35.0
April 7 - April 13	53 x 10^6	0.064	3.4
April 14 - April 21	53 x 10^6	0.056	3.0
April 22 - April 30	47 x 10^6	0.165	7.7
May 1 - May 8	40 x 10^6	0.390	15.6
May 9 - May 16	54 x 10^6	0.398	21.5
May 17 - May 23	45 x 10^6	0.278	12.1
May 24 - May 29	26 x 10^6	0.130	3.5
May 30 - June 6	31 x 10^6	0.119	3.6
June 7 - June 15	33 x 10^6	0.094	3.1
June 16 - June 30	83 x 10^6	0.081	6.8
July 1 - July 10	7 x 10^6	0.041	0.3
July 11 - July 17	14 x 10^6	0.051	0.7
July 18 - July 25	7 x 10^6	0.037	0.3
July 26 - August 1	3 x 10^6	0.061	0.2
			116.8 kg/5 months

The combined flows for Holley and Powell Creeks were estimated at 50 percent of Dragon Creek. Annually, Holley and Powell Creeks contributed approximately 20 kilograms of phosphorus to the lake.

The total phosphorus input from all the creeks in 1980 was 150 kg.

The spring runoff in 1980 was very small (Table 5), consequently the phosphorus input would be substantially larger in years of high spring runoff. Using the runoff values for Dragon Creek in 1974 (high runoff year, Table 5), and stream phosphorus concentrations in 1980 (adjusted for periods of high flow), the estimated maximum phosphorus loading from streams would be 350 kilograms.

TABLE 14: Average Nutrient Concentrations for the Dragon Lake Inflow Streams in 1980*

Nutrients	Dragon Creek At Hydraulic Road 1103113 (ug/L)	Dragon Creek At Dragon Lake Road 1103112 (ug/L)	Dragon Creek At Dragon Lake 1103117 (ug/L)	Holley Creek At Dragon Lake Road 1103114 (ug/L)
Phosphorus				
Dissolved Inorganic Phosphorus (Orthophosphorus)	4.2 ± 1.2 (n = 11)	14.5 ± 8.0 (n = 13)	25.4 ± 11.5 (n = 13)	40.1 ± 13.1 (n = 11)
Dissolved Organic Phosphorus	4.6 ± 1.8 (n = 11)	6.8 ± 1.6 (n = 13)	12.4 ± 18.0 (n = 13)	7.5 ± 1.7 (n = 11)
Total Dissolved Phosphorus	8.9 ± 1.9 (n = 11)	21.3 ± 8.8 (n = 13)	37.9 ± 24.6 (n = 13)	47.5 ± 13.2 (n = 11)
Total Suspended Phosphorus	6.4 ± 6.5 (n = 12)	47.2 ± 72.0 (n = 13)	107 ± 130 (n = 13)	6.1 ± 4.0 (n = 11)
Total Phosphorus	15.8 ± 6.4 (n = 12)	67.3 ± 71.5 (n = 14)	140 ± 124 (n = 14)	53.6 ± 16.6 (n = 11)
Nitrogen				
Ammonia-Nitrogen	19.1 ± 3.2 (n = 11)	66.4 ± 43.8 (n = 13)	113 ± 84 (n = 13)	43.5 ± 16.6 (n = 11)
Nitrite and Nitrate-Nitrogen	84.5 ± 46.6 (n = 11)	64.6 ± 53.2 (n = 13)	96.2 ± 53.2 (n = 13)	60.9 ± 35.3 (n = 11)
Organic Nitrogen	294 ± 143 (n = 11)	533 ± 281 (= 13)	821 ± 544 (n = 13)	383 ± 147 (n = 11)
Total Nitrogen	398 ± 170 (n = 11)	665 ± 304 (n = 13)	992 ± 482 (n = 13)	486 ± 165 (n = 11)

* Summarized from Appendicies 2a - 2i.

Table 14 lists the 1980 phosphorus and nitrogen concentrations of Dragon Creek for the spring through summer period at three points: Dragon Creek at Hydraulic Road, Dragon Creek at Dragon Lake Road, and Dragon Creek at the lake (Figure 2).

Table 15 lists the rate of nutrient input between the three stations. Between Hydraulic Road and Dragon Lake Road (the middle portion of the creek) there were large increases in dissolved inorganic phosphorus, suspended phosphorus, ammonia and organic nitrogen. Dissolved organic phosphorus did not increase dramatically, and nitrite and nitrate nitrogen decreased (Table 15).

The rate at which nutrients were added to the creek between Dragon Lake Road and the lake was significantly higher than the rates for the middle part of the creek (Table 15). When compared to the middle portion of the creek the nutrient loading rates increased 190 percent for dissolved inorganic phosphorus, 290 percent for suspended phosphorus, 185 percent for ammonia, 945 percent for nitrite and nitrate nitrogen, and 130 percent for organic nitrogen (Table 15).

The 1980 sampling indicates that ranching on the mid-section of the creek added significant amounts of phosphorus and nitrogen to the lake, and that ranching on the lower portion of the creek added even larger volumes.

Nutrient loading from Holley and Powell Creeks was not well documented in 1980 as the stream flows were very low, making consistent sampling impossible. The nutrient loading from these creeks was not as important as from Dragon Creek, as the flows and nutrient concentrations were much lower. The phosphorus concentrations in Holley Creek at the Dragon Lake Road averaged 53.6 ± 16.6 µg/L ($n = 11$), of which 90 percent was dissolved (Table 14). The low percentage of suspended phosphorus may have been due to the low precipitation and runoff in 1980, and to the absence of cattle on the stream banks.

TABLE 15: Increases in Nutrient Concentrations Between the Three Water Quality Stations on Dragon Creek in 1980*

Nutrient	Loading Between Dragon Creek At Hydraulic Road And Dragon Creek Road (µg/km)	Loading Between Dragon Road And Dragon Lake (µg/km)	Percent Increase In Loading Rate
Phosphorus			
Dissolved Inorganic Phosphorus (Orthophosphorus)	3.3 ± 2.4 (n = 11)	9.6 ± 5.9 (n = 13)	190
Dissolved Organic Phosphorus	0.6 ± 0.4 (n = 11)	0.7 ± 1.7 (n = 12)**	17
Total Dissolved Phosphorus	3.9 ± 2.4 (n = 11)	14.1 ± 12.9 (n = 13)	260
Total Suspended Phosphorus	13.5 ± 20 (n = 11)	53.1 ± 86 (n = 13)	290
Total Phosphorus	16.7 ± 19.8 (n = 12)	64.6 ± 84 (n = 14)	285
Nitrogen			
Ammonia Nitrogen	15.6 ± 12.4 (n = 11)	44.3 ± 42.2 (n = 13)	185
Nitrite and Nitrate Nitrogen	-3.3 ± 16.3 (n = 11)	27.9 ± 33.1 (n = 13)	945
Organic Nitrogen	89.4 ± 74.2 (n = 11)	203 ± 251 (n = 13)	127
Total Nitrogen	95.4 ± 82.2 (n = 11)	289 ± 301 (n = 13)	200

* Summarized from Appendices 2a - 2i.
** The large value recorded on May 26, 1980 was removed from the data set because it was believed to be an anomalous value.

Low stream flows in Holley Creek prevented the collection of background stream samples above the feedlot that borders the creek. Consequently, the feedlot's influence on the creek's nutrient concentrations cannot be assessed accurately. Higher freshet stream flows are required before the effects of the feedlot can be investigated.

WIND ACTIVITY

During the summer the prevailing winds are from the south, along the long axis of the lake (Parkin, per. comm.). Because the lake is shallow, and has a weak thermocline, wind will mix the entire lake. Resuspension of particulate matter containing phosphorus following wind events can cause phosphorus concentrations to increase. On two sampling occasions, July 20 and September 10, 1980 the lake phosphorus content increased significantly. The lake phosphorus content increased by 765 kg, from a low of 840 kg on August 19, to a high of 1605 kg on September 10, 1980 (Table 10). The sampling in September was preceded by strong winds on September 5 and 7, which were recorded as high as 20 knots at the Quesnel Airport (Table 16). Less severe wind conditions preceded the 230 kg increase in lake phosphorus content observed between June 8 and July 20, 1980.

In 1980 a strong wind event occurred at the same time as the ice came off the lake (Table 16). It is estimated that the wind increased the phosphorus loading rate by as much as 1000 kg/yr. The absence of wind at the 1981 spring overturn resulted in a 44 percent decrease in spring overturn phosphorus concentration (Table 20).

The resuspension of phosphorus by wind does not alter the phosphorus retention coefficient used in the Dillon and Rigler model, because resuspension was considered to be an independent event. However, the resuspension of phosphorus must be considered in this report as it occurred prior to spring overturn, and the elevated phosphorus values were incorporated in both the Dillon and Rigler and Reckhow and Simpson models that estimate the annual phosphorus loading rate.

TABLE 16: Wind Speed and Direction at Quesnel Airport Prior to Lake Sampling*

Date	Wind Direction	Wind Speed (knots)	Duration of Event
April 18, 1980	SE	16 - 22 (G33)	1200 - 1800
July 18, 1980	S	10 - 13	0300 - 0400
July 19, 1980	S	8 - 10	1500 - 1600
July 20, 1980	S	11 - 12	1000 - 1100
August 23, 1980	S	8 - 10	1800 - 2200
August 24, 1980	SSW	18 - 31 (G41)	0230 - 3000
August 24, 1980	SSW	7 - 10	1500 - 2300
August 26, 1980	SSW	12 - 15	2400 - 0100
September 3, 1980	S	7 - 10	1600 - 6000
September 4, 1980	S	9 - 14	1000 - 1900
September 5, 1980	S	7 - 14 (G19)	1100 - 0400
September 7, 1980	SSW	7 - 13 (G20)	0000 - 0200
September 8, 1980	S	7 - 10	1900 - 2300
April 15, 1981	NE & SE	7 - 16	0000 - 0600
April 16, 1981	SE & SW	6 - 20 (G28)	0000-0800; 2100-2400
April 17, 1981	W	8 - 12	0100 - 0400
April 18, 1981	SE	5 - 6	1700 - 2400
April 19, 1981	SE	5 - 10	1900 - 2400
April 20, 1981	W	1 - 8	0000 - 0700

* Sampling dates April 19, July 20 and September 10, 1980; and April 20, 1981.

The increases in phosphorus concentration following wind events must be included in the loading calculations. The extent of the loading will vary from year to year, depending on the wind velocities and patterns during the summer and fall. The estimated loading in 1980 was 1000 kg.

LIVESTOCK

In this study we have focused on the importance of phosphorus, as it has been determined in previous sections to be the factor that controls the rate of eutrophication in Dragon Lake.

There is a limited amount of literature applicable to Dragon Lake, regarding the contribution of phosphorus from livestock operations. Consequently any attempt to estimate the actual phosphorus contributions from ranching practices will be a crude estimate at best.

The volume of phosphorus from fertilizer and manure deposition that will enter a lake or stream is determined by a combination of factors. Soil type, precipitation, tillage practices, vegetation type etc., all influence the surface and subsurface transport of phosphorus.

Two facts are clear from the literature: ranching and agricultural practices in general cause increases in nutrient contributions to freshwater systems, and surface and subsurface runoff is the mechanism of transport to the water course.

There are a number of studies that attempt to quantify the impact of agriculture on phosphorus loading. Individual studies that were investigated for this report are Converse et al. (1976); Young and Mutchler (1976); Sharpley et al. (1978); Taylor and Kilmer (1980); and Hergert et al. (1981a, 1981b). A good review of the phosphorus loading from agricultural practices, which includes some of the references mentioned above, is Reckhow et al. (1980).

Additional work by Duxbury and Peverly (1978) and Hortenstine and Forbes (1972), indicates that the phosphorus loading from agricultural practices on organic soils can be much greater than from mineral soils. Both reports attribute the increased loading to low concentrations of minerals such as Ca, Fe, Al etc. These minerals are very important because of their ability to bind inorganic phosphorus. Once inorganic phosphorus has been bound to the mineral fraction of the soil, the phosphorus becomes less soluble. The result is the removal of phosphorus from solution, and a lower phosphorus content of surface and subsurface runoff.

The volumes of phosphorus leaching from subsurface organic soils, not influenced by mineral soils, ranged from 10.5 kg P/ha to 30.7 kg P/ha (Duxbury and Peverly, 1978). Hortenstine and Forbes (1972) did not quantify nutrient loading from organic peat soils, but they concluded that the phosphorus contributions were increased because of the agricultural activities. In their particular study field fertilization did not increase phosphorus runoff. Accumulated organic phosphorus that became mineralized after land clearing, and the introduction of drainage ditches were the causes for the increased phosphorus runoff.

Although these studies cannot be directly applied to Dragon Lake, they do indicate that because of the nature of the organic soils, agricultural practices on organic soils increase the amounts of phosphorus in runoff.

Several authors note that the surface runoff from frozen or saturated soils during snowmelt or severe storm events, contributed more phosphorus (and nitrogen) than at any other time of the year (Converse et al., 1976; Young and Mutchler, 1976; and Taylor and Kilmer, 1980). The work of Sharpley et al. (1978) found a highly significant correlation between surface runoff and the extractable soil phosphorus content.

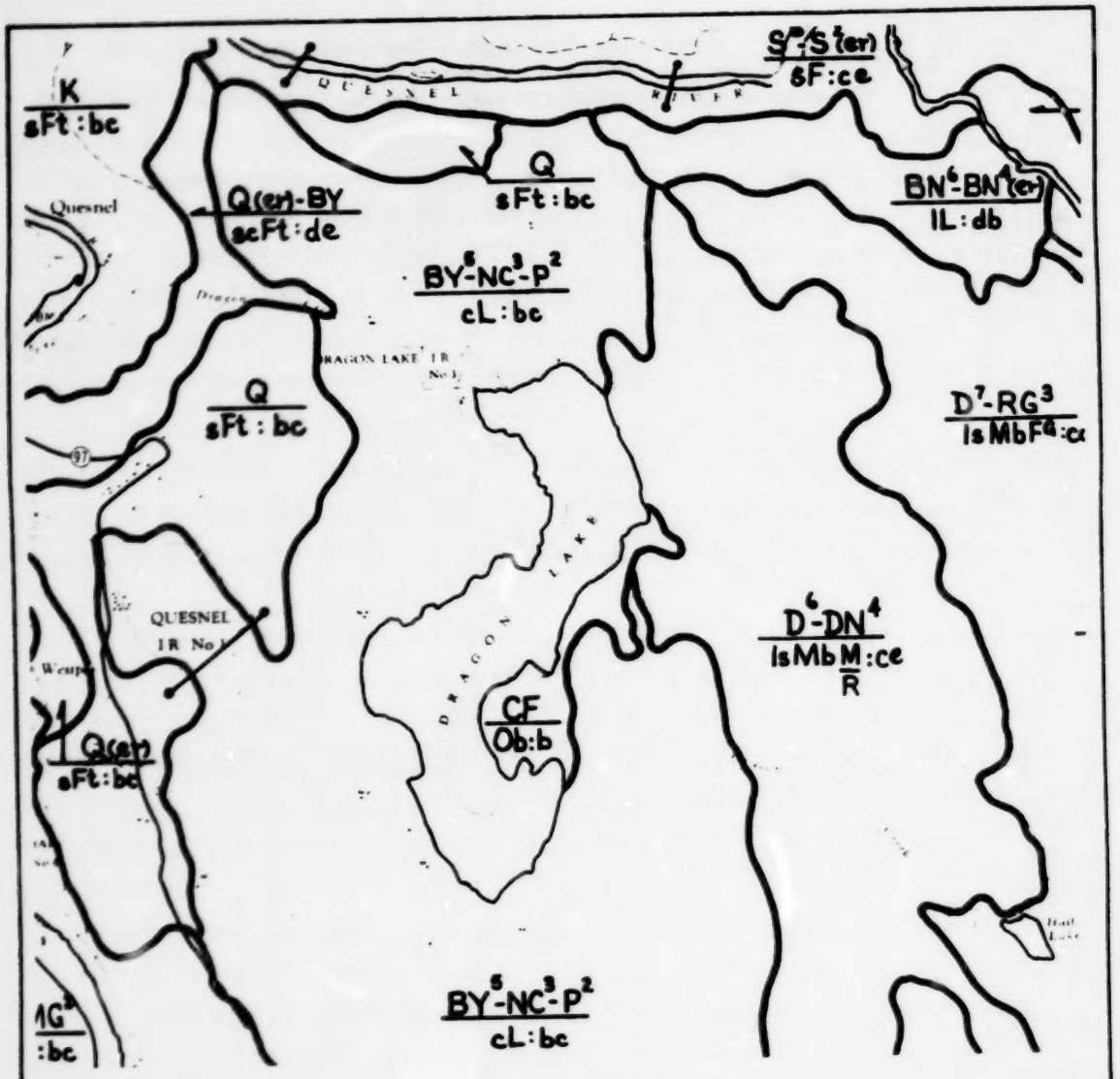
The phosphorus loading from organic soils at Dragon Lake, where ranching is practiced is expected to be high for two reasons. Firstly, rapid surface runoff will occur when the soils are frozen or saturated, or during severe storm events when rainfall exceeds the infiltration rate. Secondly, extractable phosphorus from the soil is expected to be high because of the low soil mineral content, and the long term accumulation of phosphorus from fertilization or manure deposition.

The potential phosphorus loading from cattle has been estimated using many sources (Bangay, 1976; U.S. Department of Agriculture, 1975; Agricultur Canada, 1979; British Columbia Animal Waste Management Guide, 1971; Willrich, 1976; and Miner and Willrich, 1979). The phosphorus contribution from cattle reported by the above sources, averaged 15 kg/yr for a 450 kg animal.

TABLE 17: Composite Phosphorus Transmission Coefficients used to Estimate Loadings to a Lake from Human Wastes Applied to Watershed Soils.

Waste Disposal Soil Suitability Groups	Associated Soil Type Within The Dragon Lake Watershed (See Figure 8 For Codes)	Distance Zone From Lakeshore (m)		
		0 - 60	60 - 120	>120
1	-	0.04*	0.03	0.02
2	BY-NC-P CL:bc D-DN is Mb M:ce R	0.19	0.13	0.10
3	-	0.38	0.26	0.19
4	-	0.54	0.37	0.28
5	CF ob:b	0.73	0.49	0.37

* Represents the percentage of discharged phosphorus that will theoretically enter the lake.



SOIL CLASSIFICATION

$\frac{BY^5\text{-}NC^3\text{-}P^2}{cL:bc}$	80% - Clayey lacustrine, orthic gray luvisol, moderately well drained 20% - Clayey lacustrine blanket, gleyed gray luvisol, imperfectly drained
$\frac{CF}{Ob:b}$	100% - organic materials, type mesisol, very poorly drained
$\frac{D^6\text{-}DN^4}{lsMb\ M/R\ :ce}$	60% - gravelly loam and sandy morainal, brunisolic gray luvisol, moderately well drained 40% - sandy and loamy morainal and colluvial veneer, orthic humic ferric podzol, well drained

Figure 8 SOIL TYPES IN THE DRAGON LAKE WATERSHED

The number of cattle around Dragon Lake in 1979 was estimated from conversations with trustees of the Dragon Lake Improvement District. In 1980 approximately 100 head of cattle were on the organic soils (lots 715, 2560, 3968, 3969), and an additional 30 head on the remainder of the mineral soils around the lake. Only ranches immediately around the lake were considered.

Using 15 kg P/yr/450 kg animal and 100 animals on the organic soils and 30 around the remainder of the lake, 1500 and 450 kg per year respectively of phosphorus is estimated to be deposited from livestock. Obviously not all of the 1950 kg of phosphorus deposited annually will reach the lake. It is, however, important to note that the potential phosphorus loading from livestock is 2.4 times the potential loading from septic tanks (see page 41).

Assuming the organic phosphorus from septic tanks and livestock manure is subjected to similar mineralization processes, the livestock operations were expected to contribute more phosphorus to Dragon Lake in 1980 than were septic tanks.

One can also conclude that organic soils are the least suitable for retaining phosphorus following fertilization or manure deposition. In order to minimize the impact of ranching on the organic soils, various agricultural practices are recommended and outlined on page 47.

SEPTIC TANKS

Phosphorus loading from septic tanks was based on the number of housing units around the lake, the drainage characteristics of the soil, and the distances of the septic fields from the lake (Table 18). The average number of occupants per house was estimated at 3, and the loading rate per person was 1.5 kg/yr (Wiens, pers. comm.).

The potential phosphorus loading from septic tanks was estimated to be 830 kg P/yr, of which 150 kg P/yr will theoretically enter Dragon Lake (Table 18).

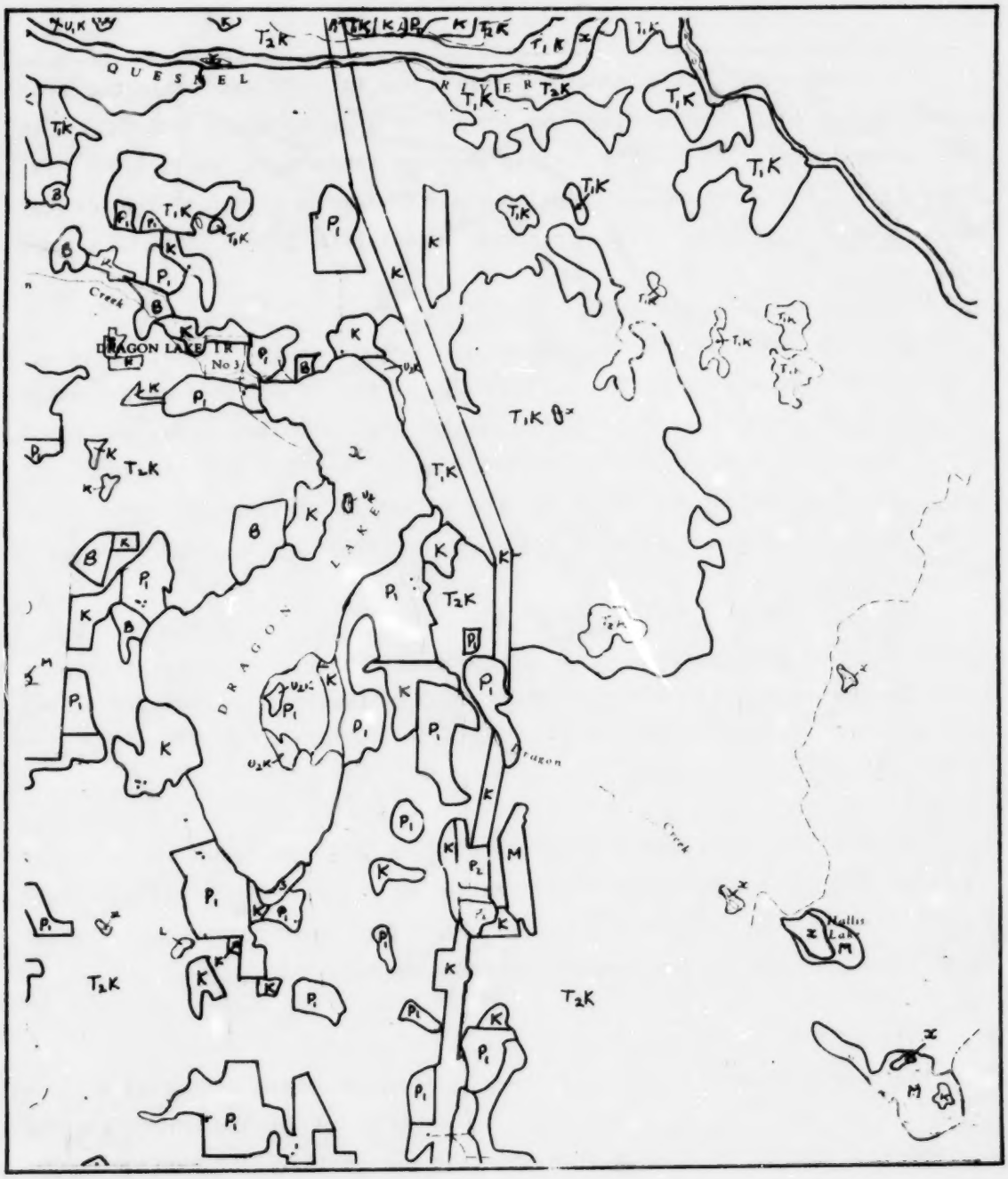


Figure 9 LAND USE WITHIN THE DRAGON LAKE WATERSHED AS SUMMARIZED BY THE CANADA LAND USE INVENTORY, 1965.*

For definition of land use symbols see Appendix 2.
* Available from B.C. Ministry of Environment
Assessment and Planning Library

TABLE 18: Calculation of Phosphorus Loading from Septic Fields

Distance From The Lake (m)	Number Of Houses	Average Number Of Occupants Per House	Loading Rate Per Person (kg/yr)	Loading Rate (kg/yr)	Transmission Coefficient To Lake*	Kilograms Of Phosphorus To Lake Per Year
0 - 60	156	3	1.5	700	0.19	133
60 - 120	29	3	1.5	130	0.13	17
				830		150

* See Table 17

AERIAL INPUT

Aerial input through dustfall or precipitation can be a significant part of the total loading to the lake. Unfortunately, limited data exist to estimate the aerial input of phosphorus. Gilliom (1980) used a total phosphorus loading value of 20 kg/km^2/yr for the Puget Sound area, Washington, while Miklas et al., (1977) measured a loading rate of 75 kg/km^2/yr in Maryland. The best estimate for Dragon Lake may be a loading rate of 30 kg/km^2/yr. Based on a 6.6 km^2 lake surface area the loading to the lake would be about 200 kg annually.

RECYCLING OF NUTRIENTS

Dissolved inorganic phosphorus (DIP) is released from the sediments during anoxic conditions. The amounts released vary depending on the duration of the anoxic period, the water temperature, pH, and several other factors. During the winter, when the lake becomes thermally stratified and anoxic, DIP concentrations increased to a maximum of 45 µg/L at seven metres. The total amount of DIP recycled was calculated to be 150 kg/yr.

FARMING

Farming is restricted to alfalfa crops on lot 3950 (Mr. E. Zechiedrich, owner), and hay on lots 715 and 3968 (for sale at present) (Figure 9). The contribution of fertilizer to the lake by leaching was estimated using

runoff values quoted in the literature by Reckhow et al., (1980); Omernik, (1977); and Converse et al., (1976).

Fertilizer application rates of 112 and 170 kg/ha/yr of 15-16-0 are commonly used around Dragon Lake (Strachan, pers. comm.). These application rates are equivalent to 7.8 and 11.7 kg/ha/yr of elemental phosphorus. The utilization of phosphorus by the harvested alfalfa crop will usually equal or exceed the fertilizer application rate (Kohlert, 1981). Consequently, the addition of phosphorus from the cultivated areas is expected to be minimal. However some phosphorus movement from soils with surface crops is quite well documented (Reckhow et al., 1980; Omernik, 1977; and Converse et al., 1976). Converse et al., (1976) noted a minimum phosphorus loading of 0.75 kg/ha/yr from a characteristically well drained, non-irrigated silt loam soil, which contained an unfertilized alfalfa crop.

The phosphorus loading from the cultivated soils around Dragon Lake is assumed to be the minimum value quoted by Converse et al., (1976) of 0.75 kg P/ha/yr. A total of 100.5 ha of watershed area immediately around the lake is under alfalfa cultivation. The runoff loss of 0.75 kg P/ha/yr will result in an estimated phosphorus loading of 75 kg P/yr.

TOTAL INPUT

The 1980 estimated loading of phosphorus from the model developed by Dillon and Rigler (1975), predicted a loading rate of 2235 kg/yr in 1980 (Table 11). The model developed by Dillon and Rigler (1975) is able to predict the phosphorus concentration under changing loading conditions. From the predicted phosphorus concentration the general water quality of the lake can be estimated.

Each method of determining the lake's phosphorus loading has its own merits. Calculation of non-point sources not only attempts to quantify the sources, but it also allows the sources to be ranked in order of importance (e.g. Table 19). From the ranked order, lake management programs can focus on the major sources of phosphorus.

The 1980 and 1981 phosphorus loading rates for Dragon Lake, estimated by the Dillon and Rigler model, were 0.34 and 0.19 $g/m^2/yr$. The loading rates exceed the provisional permissible phosphorus loading level of 0.10 $g/m^2/yr$ recommended by Vollenweider (1968). If the loading rate was 0.10 $g/m^2/yr$ the spring overturn phosphorus concentration would be approximately 10 µg/L.

Wind activity and aerial input are natural sources of phosphorus, and little can be done to reduce loading from these sources. Significant overall reduction can still be achieved, however, if the loadings from livestock, stream transport, fertilization of crops, internal recycling from lake sediments, and septic tanks are reduced. The importance of management techniques designed to minimize each source of phosphorus should be reflected by the ranking presented in Table 19.

TABLE 19: Summary of the Annual Phosphorus Loading to Dragon Lake

Sources Of Phosphorus	Estimated Loading In 1980 (kg)
Wind Activity at Spring Overturn	1000
Livestock	Not Estimated
Aerial Input	200
Septic Tanks	150
Inflow Streams	150
Recycling from Sediments	130
Crops	75

DISCUSSION

A workshop with the Trustees of the Dragon Lake Improvement District, and various representatives of the Provincial Government was held at the Government Building in Quesnel on April 30, 1981. The purpose was to discuss the findings of the 1980 water quality sampling, and recommend action to improve the present water quality. Appendix 5 lists the agencies and representatives attending the workshop.

Problems concerning the lake and the watershed, discussed at the workshop, were:

1) Dense blooms of floating blue-green algae occur on the lake throughout the summer. The blue-green algae are also suspected of causing the 'muddy' taste in trout during the summer months.

   (The cause of the nuisance algae in the summer is the elevated phosphorus concentrations and very low silica concentrations in the lake).

2) Low summer flows in Dragon Creek strand spawning adults and migrating fry, resulting in death.

   (The cause is the small watershed area to lake volume ratio and no glacial melt to augment the low summer flows).

3) Chance of winter-fish-kill is increasing with increased eutrophication.

   (The cause is increased lake production caused by high lake phosphorus concentrations).

The low stream flows in Dragon Creek during the summer can be increased by the release of stored water. The feasibility of such a program is being investigated by the Williams Lake office of the Fish and Wildife Branch, Ministry of Environment.

Because Dragon Lake is shallow, it is susceptible to a great deal of aquatic plant growth. The topic was not discussed extensively at the workshop because, although some people consider it a nuisance, the growth has not increased notably over the past several years (Zschiedrich, pers. comm.).

Keeping the lake free from Eurasian water milfoil and other nuisance aquatic plants was a concern of the Improvement District. These concerns have been directed to the Littoral Studies Section of the Aquatic Studies Branch, Ministry of Environment.

Reduction of nuisance algae and winter kill situations can only be accomplished by reducing the concentration of phosphorus in the lake. Dilution and flushing of phosphorus now present, or reduction of the present loading rate are the two possible approaches.

FLUSHING

Flushing of the lake by diversion of Schiste Creek or another water source would not only dilute the impact of the present phosphorus loading, but would also add a significant volume of silica to the lake system. The increased silica concentrations would allow diatom algae to become more prominent in the phytoplankton community.

The volumes of water required to flush Dragon Lake are quite substantial however. Using the Dillon and Rigler model, the flushing rate would need to be once per year in order to reduce the 1981 spring overturn phosphorus concentrations to the levels recommended by Vollenweider (1968) (Table 12). The volume of water available from Schiste Creek, in an average precipitation year, is only 2 percent of the water required to increase the flushing rate from 17 years to one year.

The Quesnel River is the only large water supply of suitable quality near Dragon Lake. The volume of water required to increase the flushing

rate to once per year is 35,700 dam^3/yr, or a mean annual flow rate of 68 m^3/min.

It is recommended that a cost-benefit analysis be conducted to estimate the long-term benefits of the project. This recommendation is based on the value of Dragon Lake as a drinking water supply, recreational and sports fishing lake, and its value to the Fish and Wildlife Branch as a source of rainbow trout eggs for British Columbia hatcheries. In 1980, 1.5 million eggs were collecied from Dragon Lake. These represent approximately 33 percent of all rainbow trout eggs collected in British Columbia (Leggett, pers. comm.).

METHODS OF REDUCING PHOSPHORUS LOADING

The alternate way of reducing the phosphorus concentrations in the lake is to reduce the phosphorus loading rate. The sources of phosphorus are listed in decreasing order of importance in Table 20. Different management techniques designed to reduce the loading rate are listed in Table 21 and discussed in detail below.

Table 20: Sources of Phosphorus and Method of Transport to Dragon Lake

Phosphorus Source	Method of Transport to Lake			
	Natural	Groundwater	Streams Or Surface Movement	Within Lake
Wind	✓			
Livestock			✓	
Septic Tanks		✓		
Crop Fertilization		✓		
Recycling from Sediments				✓
Aerial Input	✓			

1. Livestock

Livestock form the largest group of unnatural contributors of phosphorus to Dragon Lake. Consequently, the implementation of management techniques designed to reduce the impact of the livestock on the lake should be emphasized.

Methods designed to minimize the phosphorus loading from livestock were obtained from Cahill and Pierson (1979); International Joint Commission; International Reference Group on Great Lakes Pollution from Land Use Activities (1978); Phosphorus Management Strategies Task Force (1980); and the B.C. Ministry of Agriculture.

The management techniques applicable to livestock around Dragon Lake are as follows.

1.1) A buffer zone of a surface crop or grass should border the lake and streams to intercept some of the surface and subsurface flow of phosphorus. A buffer zone of 6-10 m has been noted by Cahill and Pierson (1979) to be effective.

1.2) The livestock should be fenced from the creeks and lake. This step will improve bank stabilization and limit direct entry of manure into the water. Watering troughs should be required away from the creek.

1.3) Overwintering of cattle at concentrations between 1 and 20 animal units/acre* should be as far away from a stream access as possible. Washing of manure into the stream during spring melt will thus be minimized.

1.4) General guidelines for control of water pollution by beef livestock operations, outlined by the Agricultural Engineering Branch of the B.C. Ministry of Agriculture, should be observed.

2. Septic Tanks

Septic tanks also contribute significant volumes of phosphorus to the lake. Generally, the major problem comes from faulty systems. Some possible management techniques are:

* 1 animal unit = 450 kg animal

2.1) Replace all existing waste disposal units with a sewer system.

2.2) Maintain existing septic tanks as best as possible either voluntarily or through the formation of a 'Waste Disposal Association.'

2.3) Institute a 'pump and haul' program. The sewage would be collected in tanks and hauled to a specific location for disposal. Water from other household sources could still be disposed of through the tile field with minimal impact on the lake's water quality.

Waste Disposal Associations have been successful in rural areas when the cost of a sewer system is considered too high. Publications listing the design and success of 'Waste Disposal Associations' are Senn (1978), Staato (1979), and Winneberger and Anderman (1972).

In the absence of a sewer system, new subdivisions in the watershed can include local sewage collection and treatment plants. The community collection system will eliminate the need for individual septic tanks, or a sewer system. The advantages are:

1) Usually a cheaper cost per housing unit.

2) A centralized system which is easier to maintain.

3) If designed properly, a reduced impact on the phosphorus loading rate.

To assess the present impact of septic tanks on Dragon Lake, sampling of coliform bacteria is proposed in areas where possible septic influence was detected. The results of the April 1981 field testing by the Terrestrial Studies Branch, Ministry of Environment, will be forwarded to the Regional Health Officer in Quesnel prior to the 1982 summer sampling (Suttie and Wiens, in prep.).

3. Farming

Reduction of phosphorus loading from crop fertilization can be accomplished by:

3.1) Testing soils throughout the watershed. If no phosphorus is required for crop production, reduce fertilization accordingly, particularly in areas next to the lake or streams.

3.2) Leaving a strip along the creeks and the lake with no fertilization. This would serve to reduce and intercept the subsurface and surface leaching of phosphorus.

3.3) Requesting farmers to maintain proper irrigation practices in order to reduce the surface flow of water following overwatering.

Areas with organic soils and poor drainage characteristics are easily overwatered. Reduction of the surface flow will reduce the rate at which phosphorus is transported from fertilized fields to the lake.

4. Recycled Phosphorus

The last source of phosphorus that can be reduced is the internal recycling during anoxic conditions. This source could theoretically be eliminated by the installation of an aerator that would prevent the anoxic conditions from occurring.

The effectiveness of aerators is severely limited in shallow lakes. Consequently, it would not be practical to install such a system in Dragon Lake (except in winter if the intent was to maintain oxygen concentrations for fisheries habitat - rather than altering water quality.).

Reduction of the biochemical oxygen demand in the hypolimnion during the winter is an alternate method of eliminating the formation of anoxic conditions. This can be accomplished by reducing the lake's phosphorus concentration. If reduction of the phosphorus loading rate could be accomplished by management of livestock, septic tanks, and crop fertilization, then the duration of the anoxic conditions could theoretically be reduced or eliminated. Consequently, the volume of phosphorus recycled during winter stratification would decrease proportionally.

TABLE 21: Possible Techniques Designed to Reduce Phosphorus Loading from Unnatural Sources

Phosphorus Source	Possible Methods Designed to Reduce Loading				
	Proper or Reduced Fertilizer Application Around Lake and Stream Banks	Buffer Zones of Hay or Alfalfa Around Lake or Stream Banks	Lake Aeration	Management of Waste through Disposal Associations	Sewers
Livestock		✓			
Crop Fertilization	✓	✓			
Recycling from Sediments			✓		
Septic Tanks				✓	✓

The methods listed in Table 21 are suggestions from which suitable management techniques can be formulated.

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Zschiedrich, C.E. 1981. Trustee, Dragon Lake Improvement District, Quesnel, B.C.

APPENDIX 1a: Active Domestic Water Licences on Dragon Lake

Date	Conditional	Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st. Dec.	File No. Comptroller	Remarks
3 May 1971	39321	Dragon Lake	C. & J. L'Heureux	L.7 of L.3971, Pl.13396	500 gad	Dom.	7200	1974	0305214	R/W
12 May 1971	39145	Dragon Lake	J.R. & D.P. Havens	L.1 of L.5442, Pl.19044	500 gad	Dom.	7200	1974	0302564	R/W
12 May 1971	38937	Dragon Lake	L.M. & J.D. Curwen	L.12 of L.3971, Pl.12554	500 gad	Dom.	7200	1974	0305265	R/W
3 Aug. 1971	39004	Dragon Lake	W. George & H.I. Murray	L.11 of L.3971, Pl.12554	500 gad	Dom.	7200	1974	0305800	R/W
14 Sept. 1971	38937	Dragon Lake	H. & W. Hartnett	L.10 of L.3971, Pl.12554	500 gad	Dom.	7200	1974	0309036	R/W
30 Sept. 1971	39146	Dragon Lake	J.M. Hartnett	L.9 of L.3971, Pl.12554	500 gad	Dom.	7200	1974	0309089	R/W
2 Nov. 1971	39147	Dragon Lake	F.W. & A.L. Healy	L.2 of L.3967, Pl.11788	500 gad	Dom.	7200	1974	0390240	R/W
20 Jan. 1972	40499	Dragon Lake	H.K. & J.P. Flege	L.11 of L's 5442 & 7258, Pl. 15929	500 gad	Dom.	7200	1975	0309582	R/W
24 Apr. 1972	40426	Dragon Lake	J.L. & G. Lewis	L.14 of L.3971, Pl.12554	500 gad	Dom.	7200	1976	0909987	R/W
26 Jan. 1973	41353	Dragon Lake	S. & D. Allanson	L.14 of L.7258, Pl.15929	500 gad	Dom.	7200	1976	0316317	R/W
22 Mar. 1973	43560	Dragon Lake	H.J.H. Smith	L.4 of L.5442, Pl.15929	500 gad	Dom.	7200	1978	0316645	R/W
25 July 1973	44374	Dragon Lake	O. & J.R. Piasondon	L.21 of L.7258, Pl.15929	500 gad	Dom.	7200	1977	0317350	R/W
10 Aug. 1973	43561	Dragon Lake	I.G. & D.M. Pollack	L.23 of L.5442, Pl.15929	500 gad	Dom.	7200	1976	0317484	R/W
10 Sept. 1973	43562	Dragon Lake	W.H. & B.C. Patenaude	L.1 of L.3971, Pl.13396	500 gad	Dom.	7200	1976	0317810	R/W
3 Oct. 1973	43563	Dragon Lake	R.B. & I.L. Scoullar	L.3 of L.5442, Pl.15929	500 gad	Dom.	7200	1976	0322020	R/W
1 Dec. 1973	43564	Dragon Lake	M.R. & S.E. Pease	L.1 of L.3971, Pl.12554	500 gad	Dom.	7200	1976	0322239	R/W
17 Dec. 1973	3565	Dragon Lake	K. &. F. Flege	L.34 of L.5442, Pl.15929	500 gad	Dom.	7200	1978	0322303	R/W
6 Mar. 1974	46031	Dragon Lake	Alice M. Hennering	L.12 of L's 5442 & 7258, Pl.15929	500 gad	Dom.	7200	1977	0322687	R/W
18 Mar. 1974	45196	Dragon Lake	E.A. Sales	L.4 of L.3967, Pl.11788	500 gad	Dom.	7200	1977	0322752	R/W
29 Apr. 1974	44900	Dragon Lake	J.L. & Y.M. Russell	L.2 of L.658, Pl.21428	500 gad	Dom.	7200	1976	0322995	R/W
28 May 1974	43566	Dragon Lake	F.D. & A.H. Jones	L.10 of L.39.67, Pl.11788	500 gad	Dom.	7200	1977	0323153	R/W
4 July 1974	46928	Dragon Lake	G.F. Pumfrey	L.6 of L.3965, Pl.10211	500 gad	Dom.	7200	1977	0323406	R/W
4 July 1974	46704	Dragon Lake	J.M. & D.G. Good	L.24 of L.5442, Pl.15929	500 gad	Dom.	7200	1977	0323410	R/W
11 July 1974	46929	Dragon Lake	J.D. Johnson	L.9 of L.3967, Pl.11788	500 gad	Dom.	7200	1977	0323827	R/W
23 July 1974	46700	Dragon Lake	P.R. Gook	that pt. of L.A of L.6677, Pl.6381, lying W. of rd. shown on said Pl.	500 gad	Dom.	7200	1977	0323828	R/W
9 Aug. 1974	46701	Dragon Lake	R.L. & K.H. Selders	L.1 of L.658, Pl.21428	500 gad	Dom.	7200	1977	0323836	R/W
15 Nov. 1974	47210	Dragon Lake	A.K. Hill	L.23 of L.3965, Pl.10211	500 gad	Dom.	7200	1980	0328131	R/W

APPENDIX Ia (cont'd)

Date	Licence Conditional	Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st Dec.	File No. Comptroller	Remarks
29 Nov. 1974	46930	Dragon Lake	J.W. & F.M. Macallister	L.18 of L.3965, Pl.10211	500 gad	Dom.	7200	1977	0328204	R/W
7 Apr. 1975	46705	Dragon Lake	Otto & Doris Siewert	L.2 of L.658, Pl.21953	500 gad	Dom.	7200	1977	0328602	R/W
6 May 1975	46733	Dragon Lake	P.D. & J.E. Daniell	Frac.W1/2 of W1/2 of L.4518	500 gad	Dom.	93 B 098	1979	0328767	R/W
18 May 1975	46931	Dragon Lake	E.M. Byrd & H.R. Olson	L.7 of L.3971, Pl.12554	500 gad	Dom.	7200	1979	0328845	R/W
14 Aug. 1975	46703	Dragon Lake	J.T. & J.M. Richardson	L.10 of L.3967, Pl.13568	500 gad	Dom.	7200	1978	0329355	R/W
27 Oct. 1975	46699	Dragon Lake	M.E. Nieman	L.2 of L.5442, Pl.159[illegible]	500 gad	Dom.	7200	1978	0329809	R/W
31 Oct. 1975	46932	Dragon Lake	P.V. Watt	L.12 of L.3965, Pl.10211	500 gad	Dom.	7200	1979	0329808	R/W
31 Oct. 1975	46702	Dragon Lake	R.H. & J.E. Graham	L.7 of L.5442, Pl.15929	500 gad	Dom.	7200	1979	0329874	R/W
9 Mar. 1976	47698	Dragon Lake	G.A. Durrell	L.3967, exc. Pl.11788, 13568, 14417, 15339, 17848 & 21917	1000 gad	Dom.	7200	1978	0330268	R/W
14 Apr. 1976	47699	Dragon Lake	S.J. & R.C. Fuller	L.7 of L.3967, Pl.11788	500 gad	Dom.	7200	1978	0330406	R/W
8 May 1976	47701	Dragon Lake	J.K. & E. Wnofsky	L.10, L.5442 & 7258, Pl.15929	500 gad	Dom.	7200	1978	0330495	R/W
25 May 1976	47702	Dragon Lake	J.P. & R. McKelvie	L.15 of L.3971, Pl.12554	500 gad	Dom.	7200	1980	0330712	R/W
28 July 1976	47529	Dragon Lake	S.D. Munro	L.11 of L.3965, Pl.10211	500 gad	Dom.	7200	1978	0340053	R/W
30 Aug. 1976	48354	Dragon Lake	S.J. Seizler	L.4 of L.3965, Pl.10211	500 gad	Dom.	7200	1978	0340205	R/W
22 Sept. 1976	48355	Dragon Lake	J.A. & N.E. Mallc	L.4 of L.6677, Pl.5861	500 gad	Dom.	7200	1979	0340302	
27 June 1977	49996	Dragon Lake	D.J. & R.A. Albion	L.6 of L.3965, Pl.12982	500 gad	Dom.	7200	1979	0341499	R/W
9 Aug. 1977	50327	Dragon Lake	E.A. & K.S. Green	L.13 of L.3965, Pl.10211	500 gad	Dom.	7200	1979	0341816	R/W
4 Nov. 1977	50743	Dragon Lake	A.T. & J.D. Atkinson	L.6 of L.3971, Pl.12554	500 gad	Dom.	7200	1979	0342279	R/W
12 Jan. 1978	51087	Dragon Lake	D.J. Gock	L.1 of L.6677, Pl.21384	500 gad	Dom.	7200	1979	0342460	R/W
8 June 1979	54124	Dragon Lake	M.L. & S.L. Pearce	L.5 of L.3971, Pl.12554	500 gad	Dom.	7200	1982	0365747	R/W
3 Apr. 1980		Dragon Lake	F. Postelhoff	L.2 of L.3965, Pl.10668	500 gad	Dom.	7200		0366321	R/W
4 June 1980		Dragon Lake	P. Zulver	L.21 of L.3965, Pl.10211	500 gad	Dom.	7200		0366694	R/W

TOTAL: 25,000 gad
209 af
253 dam3

APPENDIX 1b: Active Industrial and Irrigation Water Licences on Dragon Lake

Date	Licence Conditional	Licence Final	Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st Dec.	File No.	Remarks
22 Dec. 1958	24128		Dragon Lake	Dragon Lake Improvement Dist.	The undertaking of the Dist.	control of lk. level	Ian Imp	7200	1958	0213913	
8 Feb. 1960	25759	19348	Dragon Lake	C.E. Zachiedrich	90 acs of L.3950 lying E of Cariboo Hwy (Pl.H673) and ex Pl.B6598	90 ac.ft.	Irr	93.8.098		0226521	
2 Jul. 1963	51827		Dragon Lake	H. & S. Cotter	L.2 of L.3969, 11 acs of Cariboo Dist. Pl. 20989	11 ac.ft.	Irr	7200	1980	0346342	
2 Jul. 1963	51828		Dragon Lake	G. & C. Sales	L.1 of L.3969, Cariboo Dist. Pl.20989, 11 acs	11 ac.ft.	Irr	7200	1980	0346341	
2 Jul. 1963	53699		Dragon Lake	F.J. Shkuratoff	13.1 acs., L.A of L.3968, Cariboo Dist. Pl.24570	13.1 ac.ft.	Irr	7200	1981	0250740	1st Apr. to 30th Sept.
2 Jul. 1963	53700		Dragon Lake	O.A. & M.M. Colton	13.3 acs., L.B of L.3968, Cariboo Dist. Pl.24560	13.3 ac.ft.	Irr	7200	1982	0346731	1st Apr. to 30th Sept.
2 Jul. 1963	54575	19779	Dragon Lake	M.J. & S.E. Lapiante	50 acs., L.A of Lts. 715 & 7253, Cariboo Dist. Pl.25339	50 ac.ft.	Irr	7200	1982	0250750	Sub. F.L. 19779, in pt. 1st Apr. to 30th Sept.
2 Jul. 1963	54580		Dragon Lake	H. & J.P. Feige and G. & T. Vicker	50 acs., L.C of L.2560, Cariboo Dist. Pl.25339	50 ac.ft.	Irr	7200	1982	0367522	Sub. F.L. 19779, in pt. 1st Apr. to 30th Sept.
Approval 1969			Dragon Lake	H.C. Price of Canada Ltd.	Approval to use 850 000 gallons within L.3966	850 000 gal.		93.8.078		0338969	
25 Apr. 1975	48054		Dragon Lake	I.B. Cleave	0.5 ac. L.2 of L.3443, Pl.6192	1.0 ac.ft.	Irr	7200	1978	0328763	1st Apr. to 30th Sept.
30 Apr. 1976	47700		Dragon Lake	Royal Canadian Legion	L.1 of L.858, Pl.21953	1500 gpd	(d) Ind.	7200	1978	0330483	R/W

TOTAL: 271 af
334 dam³

APPENDIX 1c: Active Domestic Water Licences on Dragon Creek

Date	Licence Conditional	Licence Final	Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st Dec.	File No. Comptroller
3 Oct. 1967	33195	21465	Dragon Creek	E.F. Ward	Lot 715	2000 gad	Dom.	7200		0277177
14 Nov. 1967	33690	38654	Dragon Creek	W. & J. Swanky	L.A of L.7252, Pl.6091	500 gad	Dom.	938.099		0277338
17 Oct. 1969	35612	40228	Dragon Creek	W. & H.P. Annett	W1/2 of L.7252	1000 gad	Dom.	7200		0290479
17 Oct. 1969			Dragon Creek	W. & H.P. Annett	W1/2 of L.7252		Dom.	938.099		0290479
30 May 1972	40428		Dragon Creek	S.D. & R.E. Barry	L.1 of L.12507, Pl.20206	500 gad	Dom.	938.099	1975	0310187
21 Jan. 1980			Dragon Creek	J. & J. Michel	L.2 of L.9128, Pl.20835	500 gad	Dom.	938.099		0355946

TOTAL: 4500 gad
38 af
47 dam^3

APPENDIX 1d: Active Irrigation and Storage Water Licences on Dragon Creek

Date	Licence		Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st Dec.	File No.	Remarks
	Condi-tional	Final									
12 June 1941	54574	13303	Dragon Creek	M.J. & S.E. Lapiante	25 acs., L.A of Lts.715 & 7253, Pl.25539	25 ac.ft.	irr	7200	1984	0143811	Sub. F.W.L.13303 Inpt. 1st Apr. to 30th Sept.
12 June 1941	54578		Dragon Creek	T.R. & J.F. Moffat and D.A. & J.D. Holley	8.5 acs., th.pt. of L.B, Pl.25539, lr. within L.2560	8.5 ac.ft.	irr	7200	1984	0367521	Sub. F.W.L.13303 Inpt. 1st Apr. to 30th Sept.
29 May 1942	15398	13304	Dragon Creek	F.E. Ward	Store for F.L.13303	85 ac.ft.	stor	E & N 7200	1984	0146912	res on creek within D.L.9128
12 June 1941	54579		Dragon Creek	H. & J.P. Feige and G. & T. Vicker	39.7 acs., L.C of L.2560, Pl.25539	39.7 ac.ft.	irr	N 7200	1984	0367522	Sub. F.W.L.13303 Inpt. 1st Apr. to 30th Sept.
Jan. 25 1980			Dragon Creek	O. Calton	E1/2 of L.9128, Pl.22591	5 ac.ft.	irr	938.099		0355819	
Jan. 25 1980			Dragon Creek	O. Calton	Store for C.L.	5 ac.ft.	str	938.099		0355819	

TOTAL: 78 af
96 dam^3

APPENDIX 1a: Active Water Licences on Tributaries of Dragon Creek

Date	Licence Conditional	Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st Dec.	File No.	Remarks
11 June 1970	36948	Abraham Spring	E.A. Heppner	L.7254, exc. hwy. R/W	1000 gpd	Dom.	938.099	1972	0296609	
29 Aug. 1969		Atherton Creek	FULLY RECORDED - D. .R.						0285492	
13 Sept. 1972	44899	Atherton Creek	L.R. White	that pt. of L.1 of L.7261, Pl.20820 lying N. of rd.	500 gpd	Dom.	938.099	1977	0310868	
26 Nov. 1970	37744	Carolyn Brook	R.E. Cook	L.12506, exc. Pl.18041	1000 gpd	Dom.	938.099	1974	0300517	
26 June 1970	36883	Holley Spring, Chambers Brook	D.A. Holley	Lot 728	2500 gpd	Dom.	938.098	1972	0296669	
13 June 1968	34262	Mathieson Slough, Dragon Creek	W.H. & O.L. Ardell	L.7262 & E1/2 of NE1/4 of L.4518	whole flow	land imp (drain.)	938.099	1973	0281248	
23 Feb. 1970	36391	Rogers Creek	T.R. Moffat	6 acs. of L.1499	9 ac.ft. 500 gpd	Irr Dom. (S/W)	938.099	1974	0296119	
10 June 1970	36947	Rogers Creek	E.A. Heppner	L.7254, exc. hy. R/W	500 gpd	Dom. (S/W)	938.099	1974	0296389	
17 Aug. 1976		Rogers Creek	B. & E. Black	L.12531	500 gpd	Dom. (S/W)	7200		0340139	Ref. - no water
		Rogers Creek - Fully Recorded as of 1 Sept. 1977 Jav RER								
25 Jan. 1980		Spring	O. Calton	E1/2 of L.9124, Pl.22591	800 gpd	Dom.	938.099		0355818	
12 Mar. 1971	38483	Trueman Spring	Mrs. G.M. Trueman	E1/2 of L.7252, exc. Pl. 6091	1000 gpd	Dom.	938.099	1973	0300886	

TOTAL: 69 at
85 dam^3

APPENDIX 1f: Abandoned and Cancelled Water Licences

Date	Licence Conditional	Source	Licensee	Land	Quantity	Purpose	Point of Diversion	Completion 31st Dec.	File No. Comptroller	Remarks
14 Aug. 1972		Dragon Lake	M.M. Gavin	L.4,5,6, of L.3965, Pl.12982	900 gad	Dom.	7200		0310650	R/W Cancelled
5 June 1974		Dragon Lake	S. & M. Laplant	L.13 of L.7258, Pl.15929	500 gad	Dom.	7200		0323398	R/W Cancelled
30 May 1975		Dragon Lake	J.R. & J.E. McKenzie	L.1, L.3967, Pl.11788	1000 gad	Dom.	7200		0329030	R/W Cancelled
21 May 1976		Dragon Lake	R.E. & N. Morgan	L.11A, Pl.3965, Plan 1021	200 gad	Dom.	7200		0323690	R/W Cancelled
18 July 1969	36207	Dragon Creek	J. & F.S. Soroka	L.1 of L.12506, Pl.18041	500 gad	Dom.	7200	1974	0285982	Cancelled
2 May 1969	35192	Atherton Creek	E.A. Heppner	40 acs. of L.7254	40 ac.ft.	Irr.	7200	1972	0285492	Abandoned
2 May 1969	35193	Atherton Creek	E.A. Heppner	Stor. for C.L.35192	40 ac.ft.	Stor.	7200	1972	0295492	Abandoned

APPENDIX 2a: Dissolved Inorganic Phosphorus Data for Dragon Creek in 1980.

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 Aand1103112 Distance: 3.94 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate At 08HK023 Dragon Creek litres $X10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	6	10	15	1.1	4.4	300	2.25	23	34
April 27 1980	-	6	15	-	7.9	-	1.12	7	17
May 4 1980	L3	8	19	1.7	9.7	470	0.95	8	18
May 12 1980	3	13	21	2.8	7.1	154	2.07	27	43
May 20 1980	3	19	24	4.5	4.4	-2	2.68	50	64
May 26 1980	3	34	38	8.8	3.5	-60	0.69	23	26
June 3 1980	4	27	55	6.5	24.8	282	0.69	19	38
June 9 1980	4	17	37	3.7	17.7	378	0.35	6	13
June 24 1980	6	11	25	1.4	12.3	779	0.60	7	15
July 7 1980	-	9	19	-	8.8	-	0.60	5	11
July 14 1980	5	11	18	1.7	6.2	265	1.47	16	26
July 21 1980	5	12	20	2.0	7.1	255	0.69	8	14
July 29 1980	5	12	24	2.0	10.6	430	0.52	6	12
AVERAGE	4.2 ± 1.2 (n=11)	14.5 ± 8.0 (n=13)	25.4 ± 11.5 (n=13)	3.3 ± 2.4 (n=11)	9.6 ± 5.9 (n=13)	295 ± 230 (n=11)			

APPENDIX 2b: Dissolved Organic Phosphorus Data for Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Flow Rate At 08HK023 Dragon Creek litres x10^6/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	7	7	8	0.0	0.9	2.25	16	18
April 27 1980	-	6	7	-	0.9	1.12	7	8
May 4 1980	5	7	10	0.6	2.6	0.95	7	10
May 12 1980	5	6	6	0.3	0.0	2.07	12	12
May 20 1980	6	8	7	0.6	-0.9	2.68	21	19
May 26 1980	7	8	72	0.3	56.6*	0.69	6	50
June 3 1980	4	7	10	0.8	2.6	0.69	5	7
June 9 1980	6	10	10	1.1	0.0	0.35	5	5
June 24 1980	4	7	9	0.8	1.8	0.60	4	5
July 7 1980	-	6	5	-	-0.9	0.60	4	3
July 19 1980	2	6	4	1.1	-1.8	1.47	9	6
July 21 1980	3	7	6	1.1	-0.9	0.69	5	4
July 29 1980	2	3	7	0.0	3.5	0.52	2	4
AVERAGE	4.6 ± 1.8 (n=11)	6.8 ± 1.6 (n=13)	12.4 ± 18.0 (n=13)	0.6 ± 0.4 (n=11)	4.9 ± 15.6 (n=13)			

* This value is thought to be anomalous

APPENDIX 2c: Total Dissolved Phosphorus Data for Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate AT 08HK023 Dragon Creek litres $x10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	13	17	23	1.1	5.3	382	2.25	38	52
April 27 1980	-	12	22	-	8.8	-	1.12	13	25
May 4 1980	8	15	29	2.0	12.4	520	0.95	14	28
May 12 1980	8	19	27	3.1	7.1	129	2.07	39	56
May 20 1980	9	27	31	5.1	3.5	-31	2.69	73	83
May 26 1980	10	42	110	9.0	51.3	470	0.69	30	76
June 3 1980	8	34	64	7.3	26.3	260	0.69	23	44
June 9 1980	10	27	47	4.8	17.7	269	0.35	9	16
June 24 1980	10	18	36	2.3	15.9	591	0.60	11	22
July 7 1980	-	15	26	-	9.7	-	0.60	9	16
July 14 1980	7	17	22	2.8	4.4	57	1.47	25	32
July 21 1980	8	19	26	3.1	6.2	100	0.69	13	18
July 29 1980	7	15	31	2.3	14.2	520	0.52	8	16
AVERAGE	8.9 ± 1.9 (n=11)	21.3 ± 8.8 (n=13)	38 ± 24.6 (n=13)	3.9 ± 2.4 (n=11)	14.1 ± 12.9 (n=13)	297 ± 213 (n=11)			

APPENDIX 2d: Total Suspended Phosphorus Data for Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate At 08HK023 Dragon Creek litres X10^6/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	3	16	33	3.7	1[illegible].0	305	2.25	36	74
April 27 1980	-	8	143	-	119.0	-	1.12	9	160
May 4 1980	5	26	349	5.9	285.0	4730	0.95	25	332
May 12 1980	23	185	371	45.8	164.0	258	2.07	383	768
May 20 1980	14	226	248	59.9	19.0	-68	2.69	608	667
May 26 1980	2	52	20	14.1	-28.3	-300	0.69	36	14
June 3 1980	6	22	55	4.5	29.2	549	0.69	15	38
June 9 1980	7	18	47	3.1	25.7	730	0.35	6	16
June 24 1980	4	24	45	5.6	18.6	232	0.60	14	27
July 7 1980	-	8	15	-	6.2	-	0.60	5	9
July 14 1980	4	8	29	1.1	18.5	1581	1.47	12	43
July 21 1980	2	12	11	2.8	-0.9	-132	0.69	8	8
July 29 1980	1	9	30	2.3	18.6	708	0.52	5	16
AVERAGE	6.3 ± 6.5 (n=11)	47.2 ± 7 (n=13)	107 ± 130 (n=13)	13.5 ± 20 (n=11)	53.1 ± 86 (n=13)	781 ± 1408 (n=11)			

APPENDIX 2e: Total Phosphorus Data for Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase in Loading Rates	Flow Rate At 08HK023 Dragon Creek litres $X10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 12 1980	20	51	64	8.8	11.5	31	2.25	115	144
April 15 1980	16	33	56	4.8	20.4	325	2.25	74	126
April 27 1980	-	20	165	-	128.0	-	1.12	22	185
May 4 1980	13	41	390	7.9	308.0	3798	0.95	39	371
May 12 1980	31	204	398	48.8	171.0	250	2.07	422	824
May 20 1980	23	253	279	65.0	23.0	-65	2.69	680	750
May 26 1980	12	94	130	23.2	31.9	38	0.69	65	90
June 3 1980	14	56	119	11.9	55.8	369	0.69	39	82
June 9 1980	17	45	94	7.9	43.4	450	0.35	16	33
June 24 1980	14	42	81	7.9	34.5	337	0.60	25	49
July 7 1980	-	23	41	-	15.9	-	0.60	14	25
July 14 1980	11	25	51	4.0	23.0	475	1.47	37	75
July 21 1980	10	31	37	5.9	5.3	-10	0.69	21	26
July 29 1980	8	24	61	4.5	32.7	630	0.52	12	32
AVERAGE	15.7 ± 6.4 (n=12)	67.3 ± 71.5 (n=14)	140 ± 124 (n=14)	16.7 ± 19.8 (n=12)	64.6 ± 84.2 (n=14)	552 ± 1045 (n=12)			

APPENDIX 2f: Nitrite and Nitrate Nitrogen Data from Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate At 08HK023 Dragon Creek litres $X10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	160	100	120	-16.9	17.7	205	2.25	225	270
April 27 1980	-	L20	L20	-	0.0	-	1.12	22(E)	22(E)
May 4 1980	60	L20	40	-11.3	17.7	257	0.95	19(E)	38
May 12 1980	40	60	70	5.6	8.8	57	2.07	124	145
May 20 1980	40	80	120	11.3	35.4	213	2.69	215	323
May 26 1980	70	90	120	5.6	26.5	373	0.69	62	83
June 3 1980	50	80	150	8.5	61.9	629	0.69	55	104
June 9 1980	50	130	210	22.6	70.8	213	0.35	46	74
June 24 1980	70	40	80	-8.5	35.4	516	0.60	24	48
July 7 1980	-	20	40	-	17.7	-	0.60	12	24
July 14 1980	90	50	50	-11.3	0.0	100	1.47	74	74
July 21 1980	150	130	100	-5.6	-26.5	-373	0.69	90	69
July 29 1980	150	20	130	-36.7	97.3	165	0.52	10	68
AVERAGE	84.5 ± 46.6 (n=11)	64.6 ± 40.5 (n=13)	96 ± 53 (n=13)	-3.3 ± 16.3 (n=11)	27.9 ± 33.1 (n=13)	214 ± 260 (n=11)			

APPENDIX 2g: Ammonia Nitrogen Data for Dragon Creek In 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate At 08HK023 Dragon Creek litres $X10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	19	21	38	0.6	15.0	2400	2.25	47	86
April 27 1980	-	15	20	-	4.4	-	1.12	17	22
May 4 1980	16	33	121	4.8	78.0	1525	0.95	31	115
May 12 1980	21	78	116	16.1	34.0	112	2.07	161	240
May 20 1980	24	100	165	21.5	58.0	170	2.69	269	444
May 26 1980	14	120	144	30.0	21.0	-30	0.69	83	99
June 3 1980	16	112	263	27.1	134.0	395	0.69	77	181
June 9 1980	17	155	282	39.0	112.0	187	0.35	54	99
June 24 1980	22	39	62	4.8	20.4	325	0.60	23	37
July 7 1980	-	31	45	-	12.4	-	0.60	19	27
July 14 1980	18	40	46	6.2	5.3	-15	1.47	59	68
July 21 1980	20	72	54	14.7	15.0	9	0.69	50	37
July 29 1980	23	47	122	6.8	66.4	876	0.52	24	63
AVERAGE	19.1 ± 3.2 (n=11)	66.4 ± 43.8 (n=13)	113 ± 84 (n=13)	15.6 ± 12.4 (n=11)	44.3 ± 42.2 (n=13)	541 ± 773 (n=11)			

APPENDIX 2h: Organic Nitrogen Data for Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate At 08MK023 Dragon Creek litres $X10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	630	560	730	-19.8	150	857	2.25	1260	1642
April 27 1980	-	140	620	-	425	-	1.12	157	694
May 4 1980	160	400	630	67.8	203	200	0.95	380	599
May 12 1980	320	890	2000	161.0	47	-39	2.07	1842	4140
May 20 1980	280	950	2000	189.0	930	392	2.69	2555	5380
May 26 1980	330	1000	960	189.0	-35	-119	0.69	690	662
June 3 1980	100	300	530	56.5	203	260	0.69	207	365
June 9 1980	250	35	350	28.2	0.0	-	0.35	12	122
June 24 1980	230	530	610	84.7	70.8	-16	0.60	318	366
July 7 1980	-	340	370	-	26.5	-	0.60	204	222
July 14 1980	440	500	590	16.9	80.0	373	1.47	735	867
July 21 1980	290	870	600	163.8	239	46	0.69	600	414
July 29 1980	210	370	690	45.2	283	526	0.52	192	359
AVERAGE	294 ± 143 (n=11)	553 ± 28 (n=13)	821 ± 544 (n=13)	91.9 ± 78.4 (n=11)	203 ± 251 (n=13)	248 ± 3000 (n=10)			

APPENDIX 21: Total Nitrogen Data for Dragon Creek in 1980

Sampling Date	Dragon Creek At Hydraulic Road Site: 1103113 (µg/L)	Dragon Creek At Dragon Lake Road Site: 1103112 (µg/L)	Dragon Creek At Dragon Lake Site: 1103117 (µg/L)	Nutrient Change Between Sites 1103113 And 1103112 Distance: 3.54 km Units: µg/L/km	Nutrient Change Between Sites 1103112 And 1103117 Distance: 1.13 km Units: µg/L/km	Percent Increase In Loading Rates	Flow Rate At 08HK023 Dragon Creek litres $X10^6$/day	Loading Volumes At Site 1103112 gm/day	Loading Volumes At Site 1103117 gm/day
April 15 1980	810	680	890	-36.7	185	604	2.25	1530	2003
April 27 1980	-	150	640	-	433	-	1.12	168	717
May 4 1980	240	430	790	53.7	318	492	0.95	409	750
May 12 1980	380	1030	2000	183.6	858	368	2.07	2132	4140
May 20 1980	340	1130	2000	223.0	770	245	2.69	3039	5380
May 26 1980	410	1000	1220	166.0	15	17	0.69	690	841
June 3 1980	170	490	940	90.0	398	342	0.69	338	649
June 9 1980	320	630	840	87.6	185	111	0.35	220	294
June 24 1980	320	610	750	81.9	124	51	0.60	366	450
July 7 1980	-	390	450	-	53	-	0.60	234	270
July 14 1980	550	590	690	11.3	88	678	1.47	867	1014
July 21 1980	460	1070	750	172.0	-283	-265	0.69	738	518
July 29 1980	380	440	940	16.9	442	2500	0.52	229	489
AVERAGE	398 ± 170 (n=11)	665 ± 304 (n=13)	992 ± 482 (n=13)	95.4 ± 82.2 (n=11)	289 ± 301 (n=13)	359 ± 795 (n=11)			

APPENDIX 3

BRITISH COLUMBIA LAND USE CLASSIFICATION

Mapping Symbol

1. Urban. Land used for urban and associated non-agricultural purposes.

B (922) a. Built-up Areas. Land occupied by the built-up portions of cities, towns and villages, as well as isolated units away from settlements, such as manufacturing plants (e.g., gas processing), rail yards and DND property. Open fields and parks within built-up areas are included.

A (943) 2. Cropland.(b) Land used primarily for cash crops, usually in rotation but including both cash and feed grains. Oilseeds, sugar beets, potatoes, field vegetables, associated fallow and land in the process of being cleared for cultivation are included.

P (905) 3. Improved Pasture and Forage Crops. Land used primarily for the production of improved pasture, hay and other forage crops. Cultivation and planting have occurred in a recent year.

2,3. Cropland - Pasture Complex. Where large blocks of Categories 4 and 5 cannot be distinguished, the following complexes are shown on the land-use maps:

A (943)	95.0 - 100% Cropland
A_1 (943)	75.0 - 94.9% Cropland
A_2 (943)	50.0 - 74.9% Cropland
P_2 (905)	50.1 - 74.9% Improved Pasture & Forage Crops
P_1 (905)	75.0 - 94.9% Improved Pasture & Forage Crops
P (905)	95.0 - 100% Improved Pasture & Forage Crops

The subscript is determined by use of a "Cropland/Improved Pasture and Hay" ratio derived from the 1961 or 1966 Census of Agriculture and applied on a census subdivision basis. Census subdivisions are subdivided into two or more parts with different symbols only where it is known from other sources or from the photos that significant differences do exist within the subdivision.

K (918) 4. Unimproved Pasture and Range Land.

a. Open Grassland. Based on cover rather than use as not necessarily used for grazing (e.g., remote meadows). Open grassland includes grasses, sedges, herbaceous plants and scattered shrubs to four feet in height. Abandonned farms and intermittently wet hay land (sloughs) are included.

b. Open Woodland and Forest Range. These are classified as pasture and range if they are on, or contiguous with, occupied farmland or if there is evidence or knowledge of grazing activity. They are also given a woodland classification, e.g., T_2K

APPENDIX 3 (cont'd)

5. Woodland. (c) Land covered with tree or scrub growth.

T_1(909)(d) a. Mature Productive Woodland. Land bearing a productive forest type with at least one tree per acre greater than 11.1" d.b.h.

T_2(909)(d) b. Immature Productive Woodland. Productive forest land with immature cover.

U_1(913) c. Non-Productive Woodland on a Productive Site. Forest land which has been logged, burnt or diseased and has either not been satisfactorily restocked or has been restocked by a non-commercial type.

U_2(911) d. Non-Productive Woodland on a Non-Productive Site. Land bearing a non-productive type on a non-productive site.

X (901) 6. Water Surfaces. Excluding temporarily flooded hay meadows, etc.

APPENDIX 4

DEFINITIONS OF SYMBOLS AND UNITS USED IN THE REPORT

°C	- degrees Celsius
cm	- centimetres
dam^3	- cubic decametres
$g/m^2/yr$	- grams per square metre per year
ha	- hectare
kg	- kilogram
km	- kilometre
km^2	- square kilometre
mg/L	- milligram/litre
mL	- millilitre
mm	- millimetre
n	- sample size
N.T.U.	- Nephelometric Turbidity Units
T.A.C.	- Total Absorbed Colour
µg/L	- microgram/litre
$µmho/cm^2$	- micromho per square centimetre
yr	- year

APPENDIX 5

ATTENDEES OF THE WORKSHOP HELD ON APRIL 30, 1981 AT THE GOVERNMENT OFFICE, QUESNEL, B.C.

Mr. Jack Leggett	Fish and Wildlife Branch	Williams Lake
Mr. Bill Westover	Fish and Wildlife Branch	Williams Lake
Mr. Norm Zirnhelt	Waste Management Branch	Williams Lake
Mr. Don Holmes	Waste Management Branch	Kamloops
Mr. Ken Kvist	Water Management Branch	Williams Lake
Mr. Tom Smith	Water Management Branch	Williams Lake
Mr. O.J. Kettleson	Forest Service	Quesnel
Mr. Glen Smith	Cariboo Health Unit	Quesnel
Dr. John Wiens	Terrestrial Studies Branch	Victoria
Mr. Philip Johnson	Engineering Branch B.C.M.A.F.	Abbotsford
Mr. Graham Strachan	Ministry of Agriculture and Food	Quesnel
Mr. Ron Creber	Ministry of Lands, Parks & Housing	Quesnel
Dr. Richard Nordin	Aquatic Studies Branch	Victoria
Mr. Colin McKean	Aquatic Studies Branch	Victoria
Mr. Russ Kenzie	Dragon Lake Improvement Dist.	Quesnel
Mr. C.E. Zschiedrich	Dragon Lake Improvement Dist.	Quesnel
Mr. G. Murray	Dragon Lake Improvement Dist.	Quesnel
Mr. J.P. McKelvie	Dragon Lake Improvement Dist.	Quesnel
Mr. Robert Worm	Dragon Lake Improvement Dist.	Quesnel

536000

122°24'00"

53°00'00"

L.7264

L.7289

QUESNEL RIVER

L.3595

L.3594

L.3594

Blk. A

L.6687

L.6685

L.6686

INSET A

L. 3971

L. 3967

Road

17 16 15 14

13 13

19 12

20 11

21 10 9

18 12

11

16 10

15

14

13 14 15

17

16

Road

1 2 3 4 5 6

7

8

9

CL 46929

CL47699

CL 43566

CL47702

CL 40426

CL38937

CL 38938

CL 39004

CL 39321

CL 39146

CL 43562

CL 54124

CL 46931

CL 43564

CL 50743

CL 39147

CL 45196

Dragon Lake

Scale: 1 : 4800

7

18

Blk. A

L. 3949

L 11968

L. 12003

CL 37391

L.658

L.5442

L.5443

I.R. Nº 3 DRAGON LAKE

L.6676

Powell Cr.

CL 46705

CL 44900

CL 46701

CL47700

CL 46700

SEE INSET C

Blk. A

L. 7258

L.6677

CL 48355

PROVINCIAL RES. (DRAGON LAKE)

CL 51087

B.C. HYDRO

Dragon L.

5440

L 1499

L 1253

3140

Blk. B

Blk. A

L. 3971

L.3967

SEE INSET A

CL 46703

CL 47698

CL 54575

INSET

23 24 25 26 27 28 29

1 2 3 4 5 6 7 8 9

CL 43563

CL 39145

CL 43561

CL 46699

CL 46704

CL 43560

CL 46701

CL 47701

CL 40499

CL 43565

Dragon Lake

Scale: 400

544000

93·G·009

548000

NSET C

L 5442

27 28 29 30 31 32 33 34 35 36 37 38

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

CL 47701

CL 40499

CL 46031

CL 43565

CL 41353

CL 44374

ale: 400' : 1"

L 9786

QUESNEL

Blacksand Pete Cr.

Deacon CR

L.3967

Blk. B

Blk. A

L. 3971

SEE INSET A

SEE INSET B

CL46703

CL54575

CL47698

Dragon Lake

Dragon L.

HYDRO

5440

L 11499

L. 12531

Cr.

CL 36947

CL36949

FL21465

L.715

Dragon Cr.

L. 7253

CL54579

L 7254

CL36948

POWER

CL54580

L. 2560

CL54579

CL54578

L. B 2560 C

Atherton Creek

CL44899

CL51828

CL53699

L.3968

Plan 6091

AUTHORITY

HO228

FL38654 A

Dragon

L. 7252

L.3969

L.3970

L. 7261

L. 12506

CL37744

CL38483

CL53700

CL51827

A2473

CL34262

Plan 18041

Carolyn Cr.

Plan 20206

A

B

L.12507

CL40428

Mathieson Slough

L.7262

L.4518

L.7255

L. 9128

L 4133

L.3966

1969

FL19348

L.3950

CL46933

L. 728

CL36883

Holley Spring

Plan 84598

51A

L.3953

L.3963

L.3954

L.3952

L.3964

NATURAL GAS

The boundaries of DRAGON LAKE IMPROVEMENT DIST. are shown thus:
I.D. Plan 200
For licences see W.R. Map 7200
The boundaries of WOLFE WATERWORKS DISTRICT are shown thus:

The boundaries of DRAGON LAK
DISTRICT are shown thus:
For licences see W.R. MAP 72

INSET B

Highway No. 97

West Coast Transmission Pipeline

56 55 54 53 52 51 50

41 40 39 42 43 44 45 46 47 48 49

27 24 25 26 1 2 1 2 28 29 30 31 32 33 34 35 36 37 38

23 22 21 20 2 3 6 5 4 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

CL 47210

0366694

0366321

CL 49996

CL48354

CL46928

Dragon Lake

L. 3965

CL47520

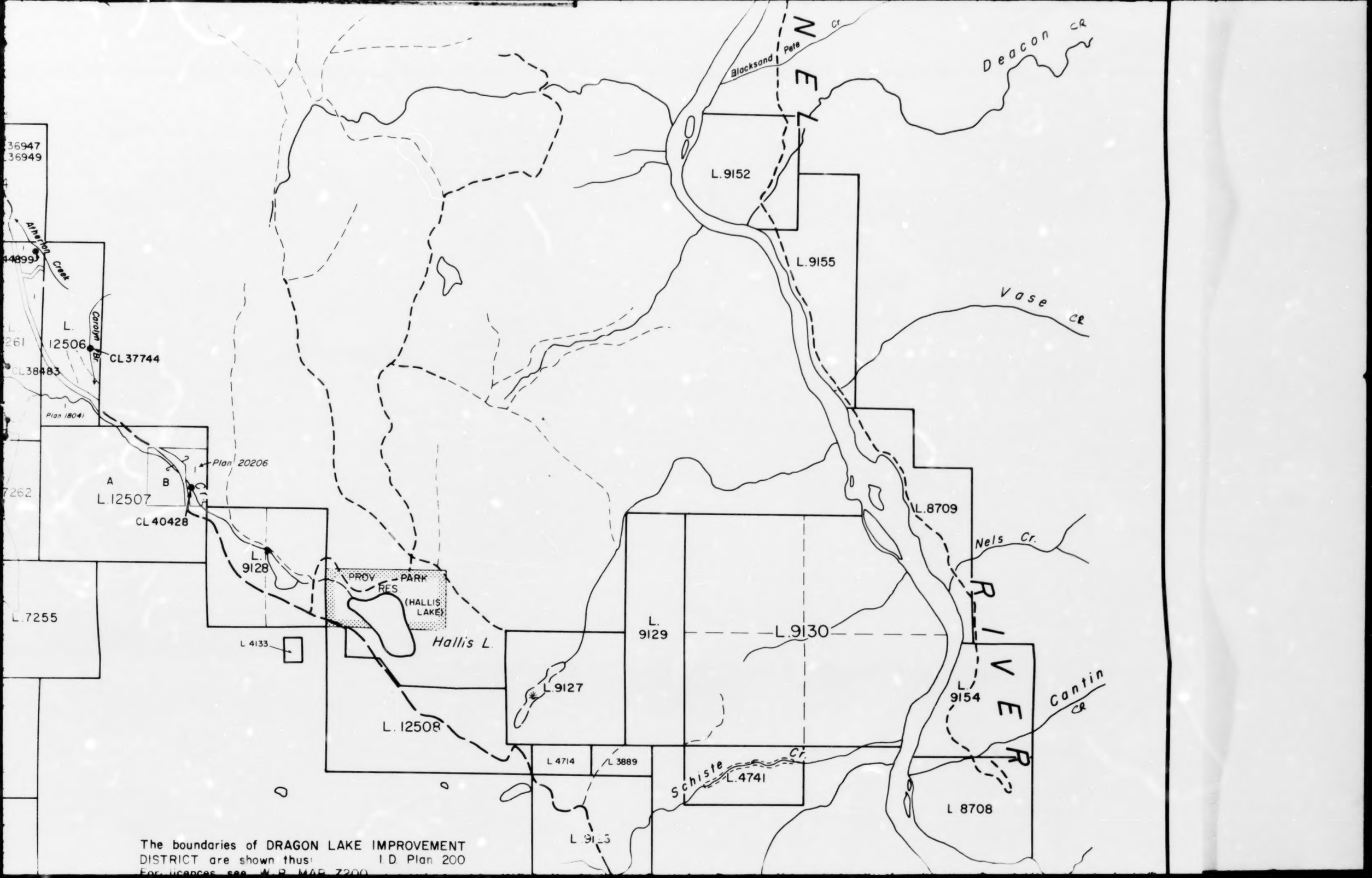
CL46932

CL50327

CL46930

.1905

CL43913


Blacksand Pete Cr
Deacon CR
L.9152
L.9155
Vase CR
36947
36949
Atherton Creek
44899
L. 12506
CL37744
Carolyn Br
CL38483
Plan 18041
Plan 20206
A
B
L.12507
CL40428
L. 9128
PROV PARK RES (HALLIS LAKE)
Hallis L.
L 4133
L.7255
L. 9129
L.9130
L.9127
L.12508
L 4714
L 3889
Schiste Cr.
L.4741
L.8709
Nels Cr.
RIVER
L. 9154
Cantin CR
L 8708
The boundaries of DRAGON LAKE IMPROVEMENT DISTRICT are shown thus: I.D. Plan 200
For licences see M.R. MAP 7200

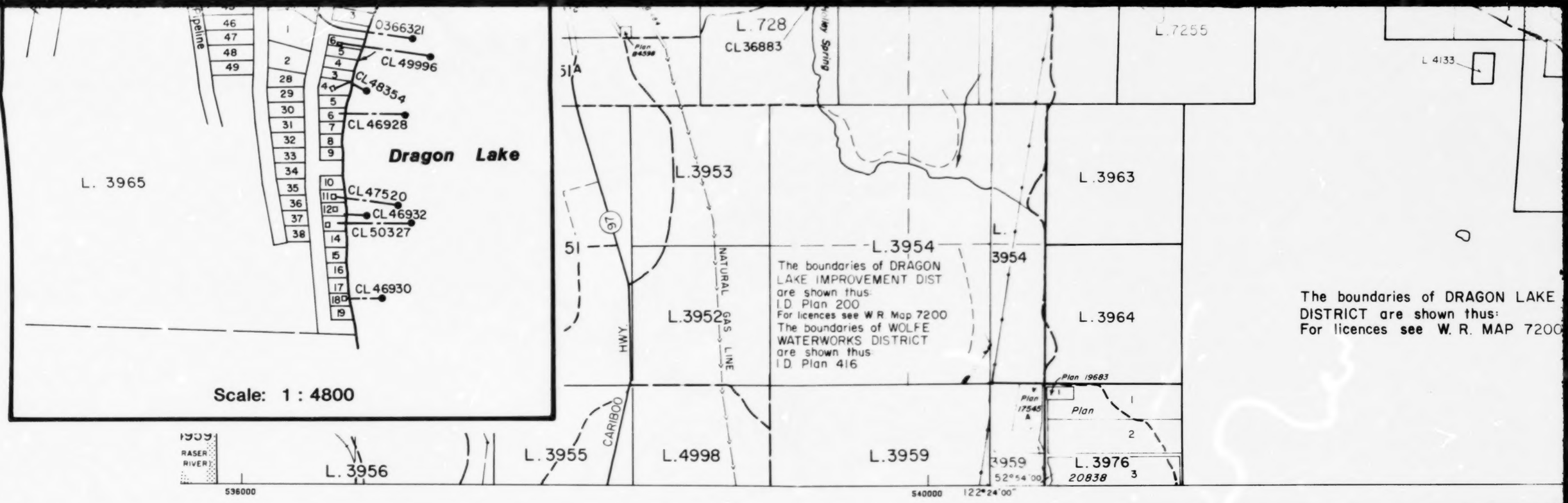
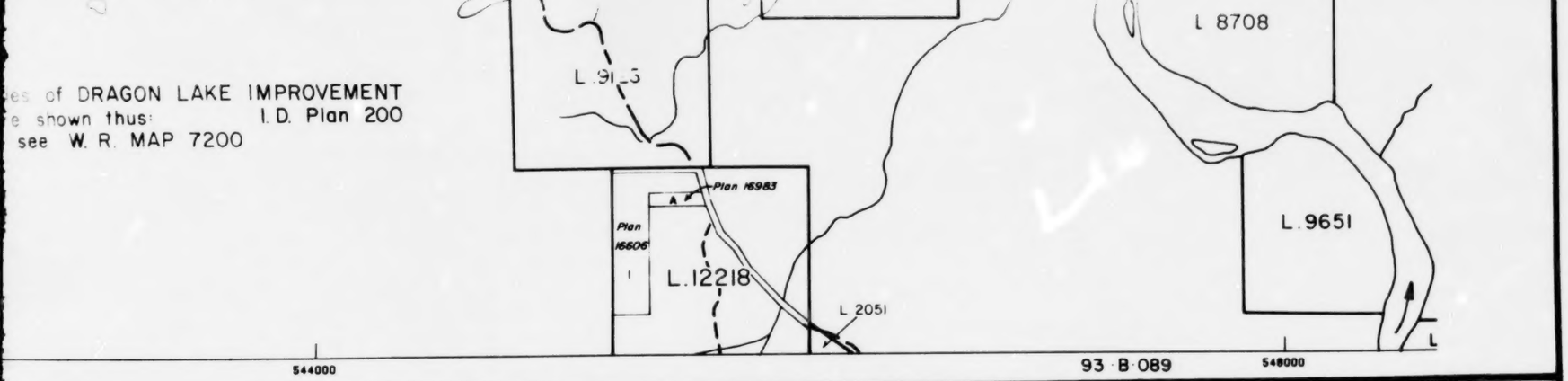


Figure 4 LOCATION OF ACTIVE WATER LICENCES WITHIN THE DRAGON LAKE WATERSHED

es of DRAGON LAKE IMPROVEMENT
e shown thus: I.D. Plan 200
see W. R. MAP 7200



93 · B · 089

TERSHED

SCALE - 1:20000

Metres 400 0 400 800 1200 1600 2000 Metres

Feet 1600 0 1600 3200 4800 Feet

WATER DISTRICT
QUESNEL

PRECINCT
COTTONWOOD

U.T.M. Zone
10